Latest Results from BESIII

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Higgs, New Physics at LHC and Dark Matter Searches

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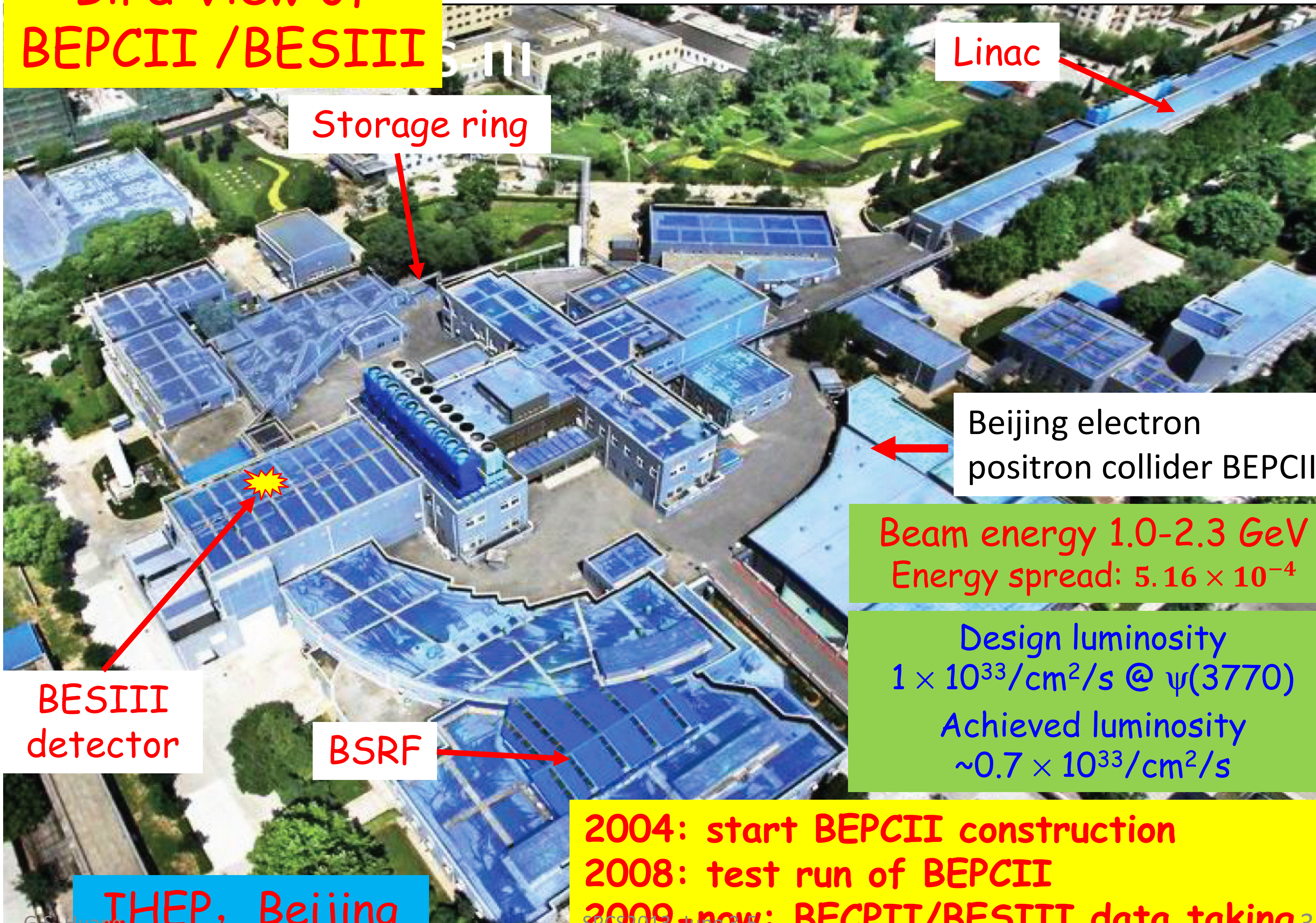
Outline

- Status of BEPCII/BESIII
- Selected Results from BESIII
  - XYZ meson study
  - Light Hadron Spectroscopy
  - Charmonium Transitions
  - Charm Decays
  - τ Mass Scan
- Summary

Bird View of BEPCII /BESIII



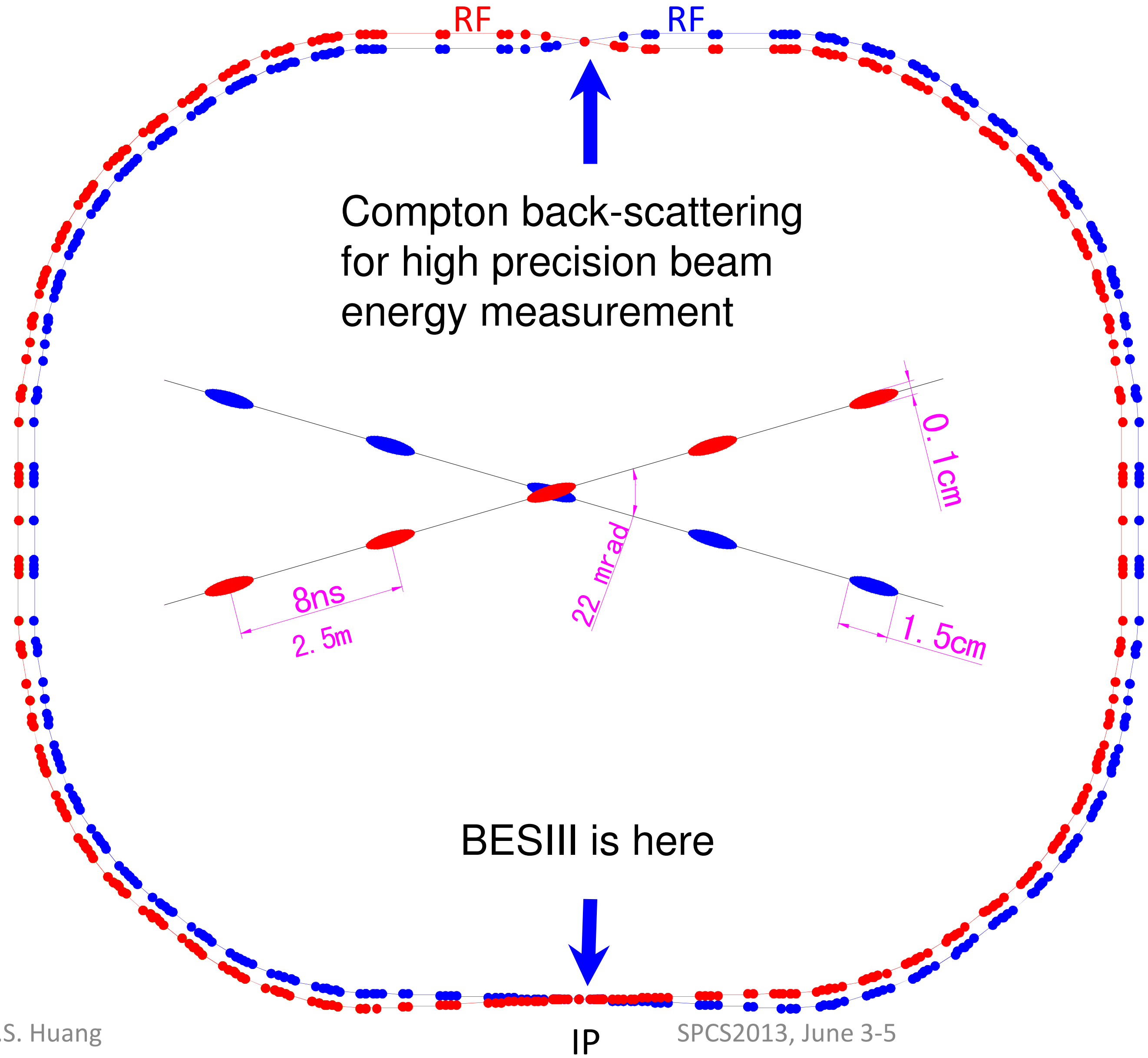
Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$

Achieved luminosity
$\sim 0.7 \times 10^{33}/cm^2/s$

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

BEPC II: Large Crossing Angle, Double-ring



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A@2.5GeV

NIM A614, 345 (2010)

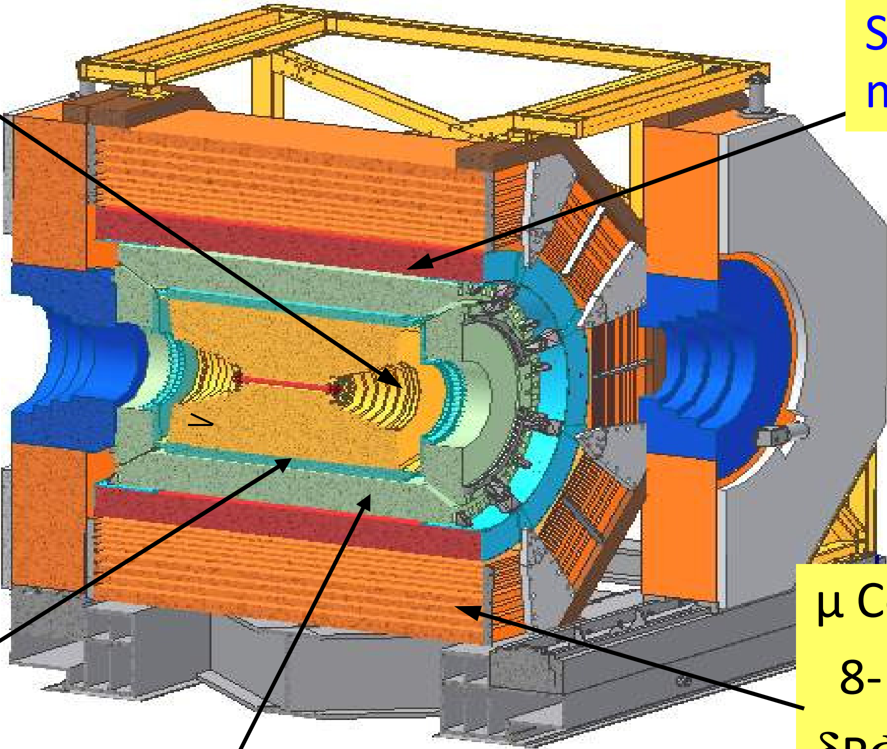
The BESIII Detector

Drift Chamber (MDC)

$\sigma p/p$ ($^0/_0$) = 0.5%(1GeV)

$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 Tesla)



Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

μ Counter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)

(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

BESIII Data Taking

- July 19, 2008: first e^+e^- collision event in BESIII
- Nov. 2008: ~14M $\psi(2S)$ events for detector calibration
- 2009: 106M $\psi(2S)$ 4×CLEO-c
  225M J/ψ 4×BESII

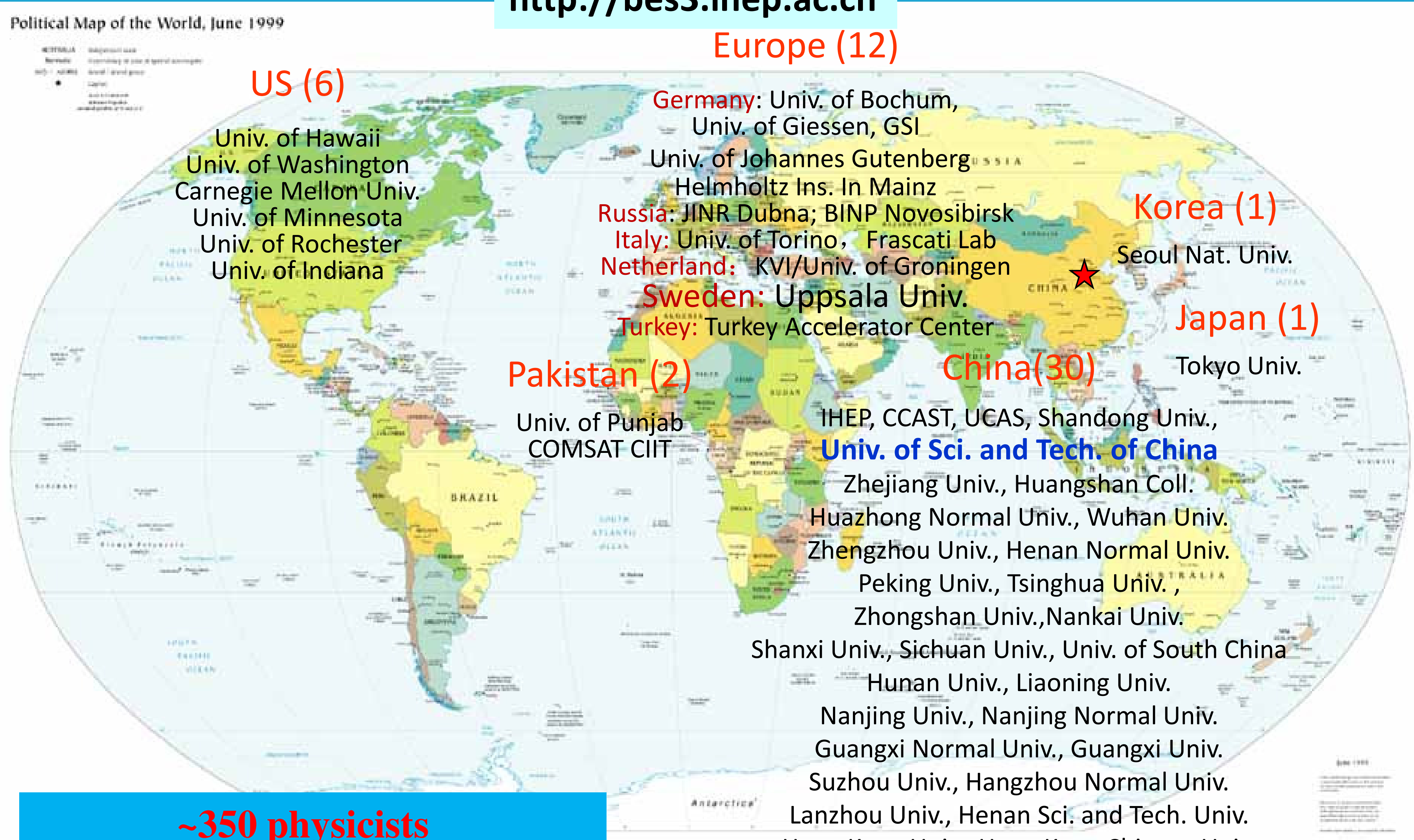
World's largest sample of J/ψ, $\psi(2S)$ and $\psi(3770)$

- 2010: ~0.9 fb^{-1} $\psi(3770)$
- 2011: ~2.0 fb^{-1} $\psi(3770)$
  } 3.5×CLEO-c
  ~0.5 fb^{-1} @ 4.01 GeV
- 2012: tau mass scan: ~22 pb^{-1} ; $\psi(2S)$: 0.4B; J/ψ: 1B; J/ψ lineshape, R scan (2.23, 2.4, 2.8, 3.4 GeV)
- 2013: ~1.0, 0.8, 0.5 fb^{-1} @ 4.23, 4.26, 4.36 GeV and scan in vicinity

Future plans: R scan, D_s physics (E_{cm}=4170 MeV), τ scan, 5-10 fb^{-1} $\psi(3770)$ for DD physics, ……

The BESIII Collaboration

http://bes3.ihep.ac.cn



US (6)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (12)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino，Frascati Lab
Netherland：KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(30)

IHEP, CCAST, UCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
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Zhongshan Univ.,Nankai Univ.
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Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.

~350 physicists

52 institutions from 11 countries

Physics Programs @ BESIII

XYZ meson physics:

- Zc in $Y(4260) \rightarrow \pi^+\pi^- J/\psi$

Light hardron physics

- meson & baryon spectroscopy
- threshold effects
- multiquark states
- glueballs & hybrids

Charmonium physics:

- precision spectroscopy
- transitions and decays

Charm physics:

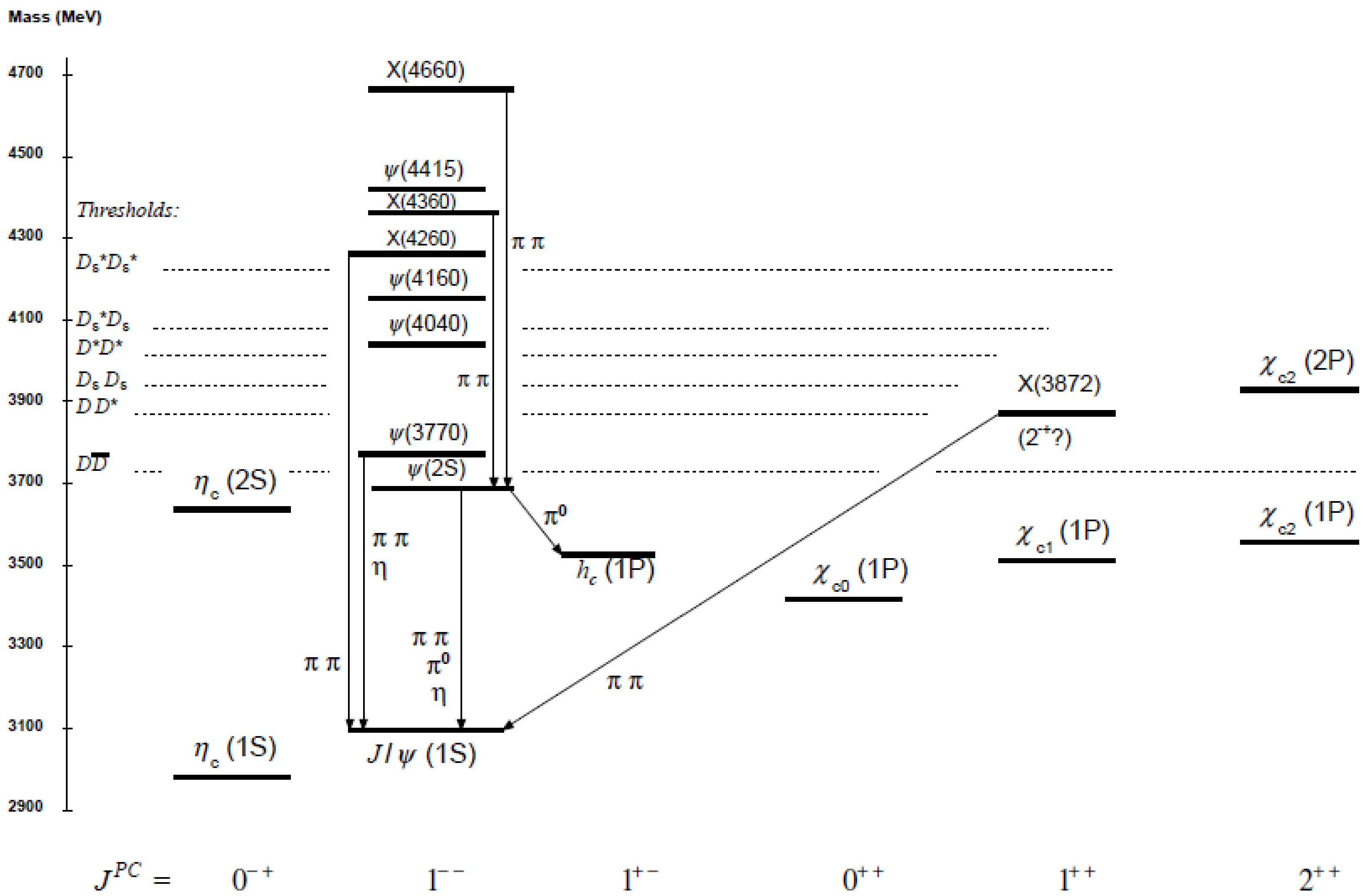
- (semi-)leptonic decays
- f_D & f_{D_s} decay constants.
- CKM matrix: V_{cd}, V_{cs}
- D^0-D^0 mixing and CPV
- strong phases

QCD & τ-physics:

- τ mass / τ decays
- precision R-measurement
- form-factors
- two-photon physics

…

The Charmonium System

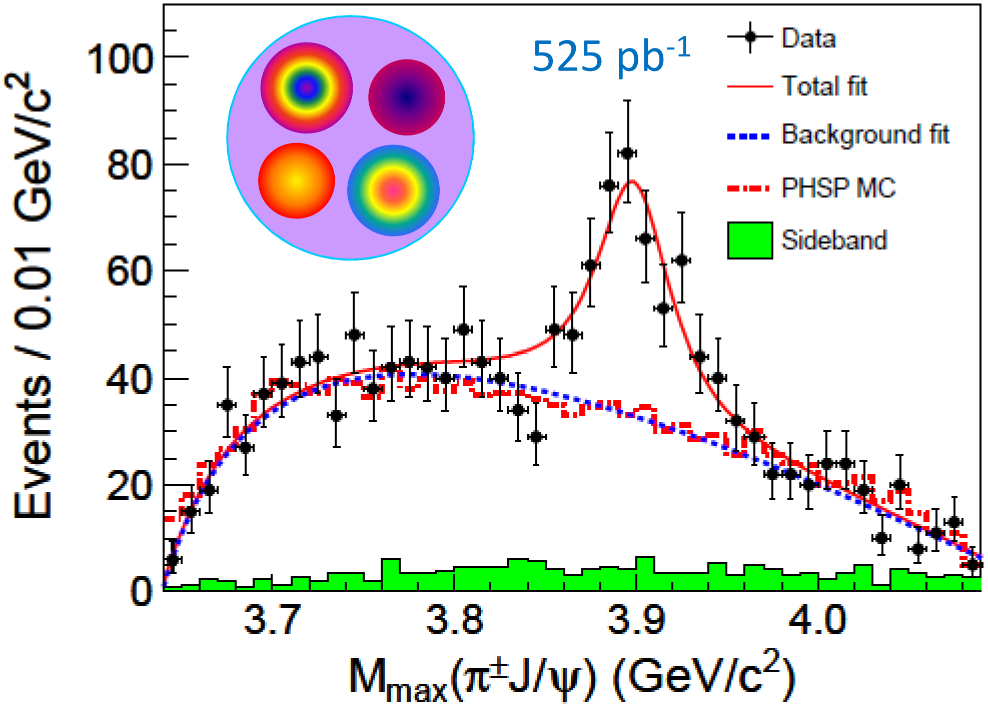


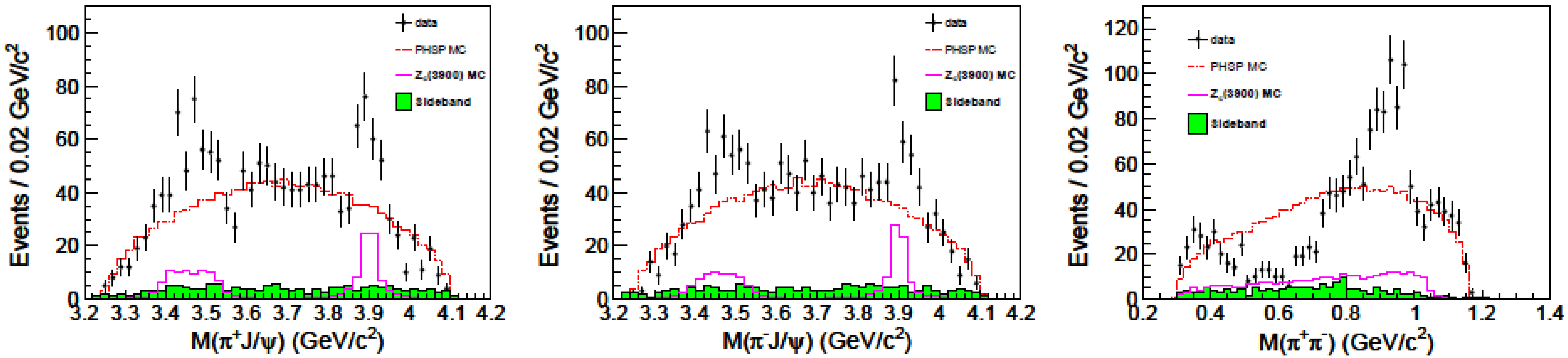
Recent Results on XYZ meson Physics

- **Observation of the Zc(3900)**

$Z_c^{\pm}$ observed at BESIII

- *Y(4260)* → $\pi^+\pi^- J/\psi$ result agrees with BaBar & Belle, better precision;
- *Zc* significance > 8σ;
- Mass (3899.0±3.6±4.9) MeV;
- Width (46±10±20) MeV;
- Quickly confirmed by Belle & CLEO-c;
- arXiv:1303.5949, accepted by PRL.

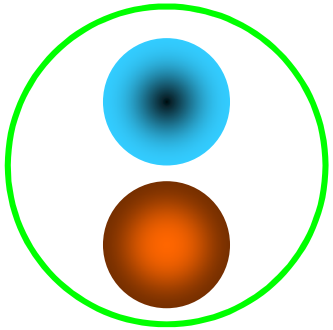




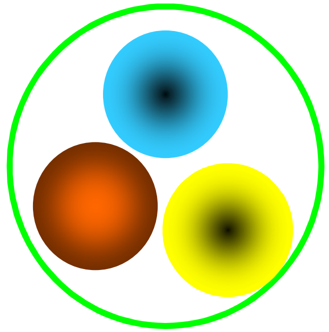
$Z_b^{\pm}$, $Z_c^{\pm}$: Exotic Hadrons

- In Quark Model, hadron has 2 or 3 quarks;

meson:
2 quarks



baryon:
3 quarks

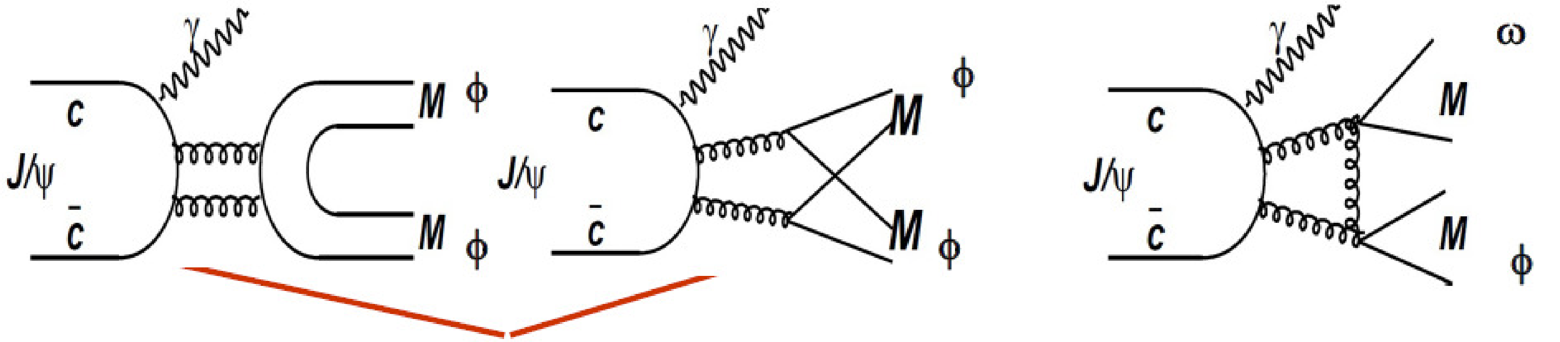


- QCD allows hadrons with $N_{quarks} \neq 2, 3$
  - glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - hybrid : $N_{quarks} = 2$ + excited gluon
  - multiquark state : $N_{quarks} > 3$
  - molecule : bound state of more than 2 hadrons
- $Z_b^{\pm}$, $Z_c^{\pm}$ are special, because they apparently have 4 quarks ($b\bar{b}/c\bar{c}$ + 2 light quarks): $\pi^{\pm}\Upsilon(nS)$, $\pi^{\pm}\psi(nS)$.

Recent Results on Light Hadron Physics

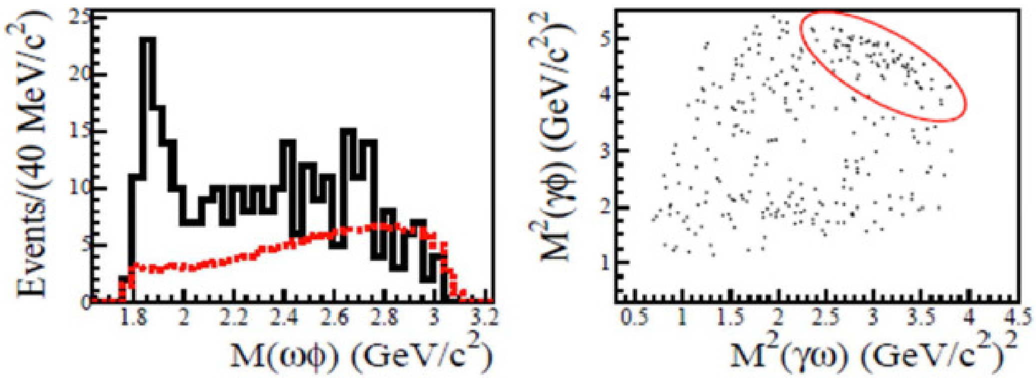
- $\omega\phi$ threshold enhancement in $J/\psi \to \gamma\omega\phi$
- $\eta\eta$ system in $J/\psi \to \gamma\eta\eta$
- $J/\psi \to \Lambda \bar{\Sigma}^0$ + c.c.

ωφ threshold enhancement in J/ψ→γωφ



$J/\psi \to \gamma\phi\phi, \phi \to K^+K^-$ **(OZI)** $J/\psi \to \gamma\omega\phi$ **(DOZI)**

BESII



$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV/c^2}$

$\Gamma = 105 \pm 20 \pm 28\ \mathrm{MeV/c^2}$

J^{PC} favors 0^{++} over 0^{-+} and 2^{++}

Phys. Rev. Lett. 96(2006)162002

PRD 87, 032008 (2013)

$J/\psi \to \gamma\omega\phi$ at BESIII

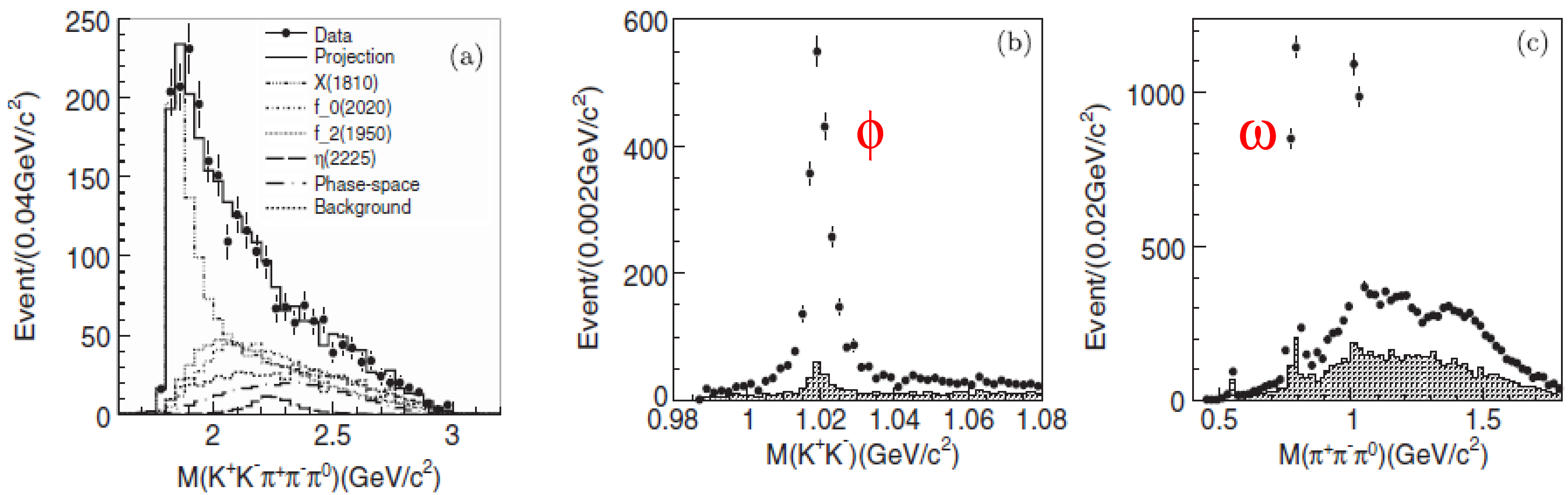
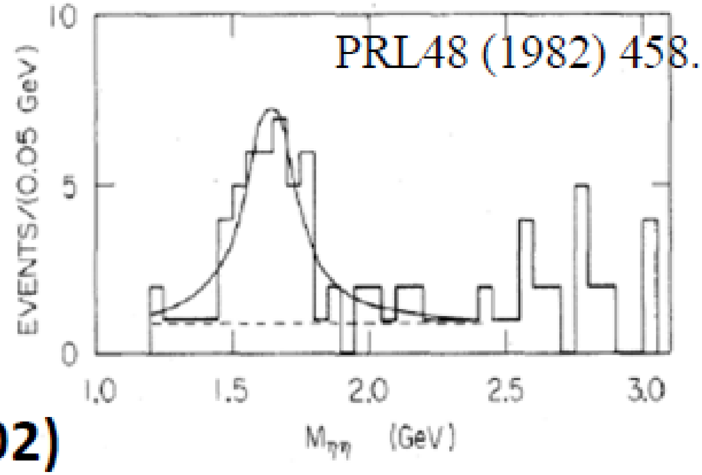


TABLE I. Results from the best PWA fit solution.

Resonance	J^{PC}	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	Events	ΔS	Δndf	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$>30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	20.4σ
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	13.9σ
$\eta(2225)$	0^{-+}	2226	185	70 ± 30	23	2	6.4σ
Coherent nonresonant component	0^{-+}	$\cdots$	$\cdots$	319 ± 24	45	2	9.1σ

Is X(1810) the $f_0(1710)/f_0(1790)$ or a new state?

Study of $\eta\eta$ System



- **First observed $f_0(1710)$ from**
- **J/ψ radiative decays to $\eta\eta$ by Crystal Ball in 1982.**

- **Crystal Barrel Collaboration (2002) analyzed the three final states $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$ with K matrix formalism. Found a 2^{++} (~1870), but no $f_0(1710)$.**

- **E835 (2006): ppbar → $\pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$.**

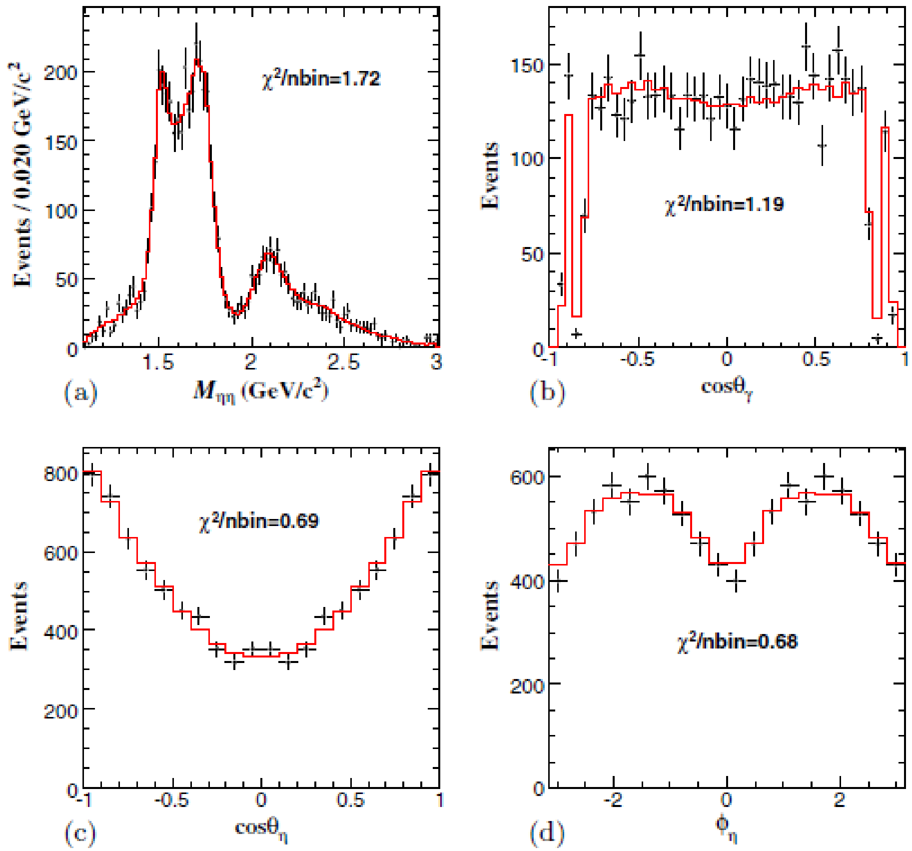
- **WA102 and GAMS all identified $f_0(1710)$ in $\eta\eta$.**

PRD 87, 092009 (2013)

$J/\psi \to \gamma\eta\eta$ at BESIII:

LQCD: lowest mass glueball with 0^{++} is in 1.5-1.7 GeV

- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- $f_2'(1525)$ is the dominant tensor



Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

PRD 86, 032008 (2012)

$J/\psi \rightarrow \Lambda \bar{\Sigma}^0$ + c.c.

- PDG2010: $Br(J/\psi \rightarrow \Lambda\bar{\Sigma}^0) < 1.5\times10^{-4}$
- First observation
- Study isospin breaking mechanism in $J/\psi \rightarrow \Lambda\bar{\Sigma}^0$ + c.c.
- Search for $\Lambda(1520)\rightarrow\gamma\Lambda$
- Measured $\eta_c \rightarrow \Lambda\bar{\Lambda}$ (Only observed by Belle in $B \rightarrow \Lambda\bar{\Lambda} K$ before)

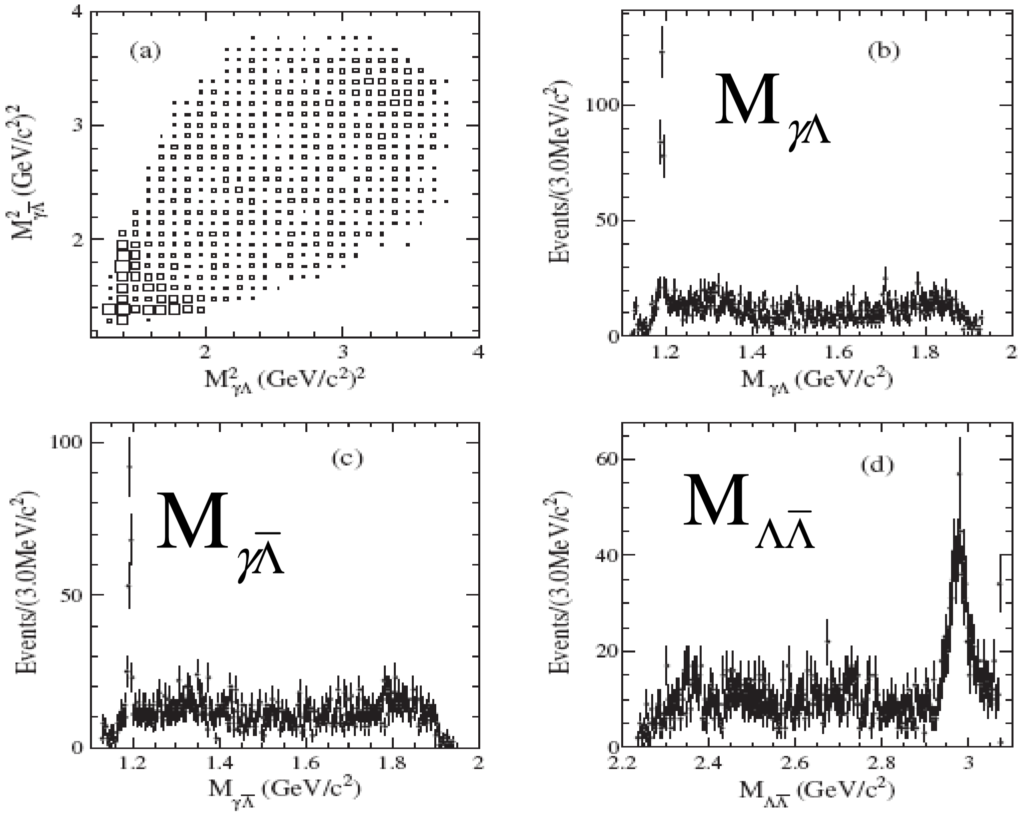


TABLE Branching fractions (10^{-5})

J/ψ decay mode	BESIII	PDG
$\bar{\Lambda}\Sigma^0$	$1.46 \pm 0.11 \pm 0.12$	<7.5
$\Lambda\bar{\Sigma}^0$	$1.37 \pm 0.12 \pm 0.11$	<7.5
$\gamma\eta_c(\eta_c \rightarrow \Lambda\bar{\Lambda})$	$1.98 \pm 0.21 \pm 0.32$	$\cdots$
$\Lambda\bar{\Lambda}(1520)$ + c.c.$(\bar{\Lambda}(1520) \rightarrow \gamma\bar{\Lambda})$	<0.41	$\cdots$

Recent Results on Charmonium Physics

- Observation of $\psi(2S) \to \gamma\eta_c(2S)$
- $e^+e^- \to \eta J/\psi$ @4.009 GeV
- $\psi(2S) \to \eta J/\psi$, $\pi^0 J/\psi$
- $\psi(2S) \to K^+K^-\pi^0$, $K^+K^-\eta$
- $\psi(2S) \to p\bar{p}\pi^0$
- $\chi_{cJ} \to \Lambda\bar{\Lambda}\pi^+\pi^-$
- $\chi_{cJ} \to \Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$, $\Sigma^+\bar{\Sigma}^-$
- $\chi_{cJ} \to p\bar{n}\pi^-$, $p\bar{n}\pi^-\pi^0$

$\eta_c(2S)$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi(2S)\to\gamma X$, never confirmed by other experiments.)

- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^\pm \to K^\pm \eta_c(2S), \eta_c(2S) \to K_S K^\pm \pi^\mp$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12\pm3$ MeV

- The M1 transition $\psi(2S)\to\gamma\eta_c(2S)$ has not been observed.

(experimental challenge : search for real photons ~50MeV,)

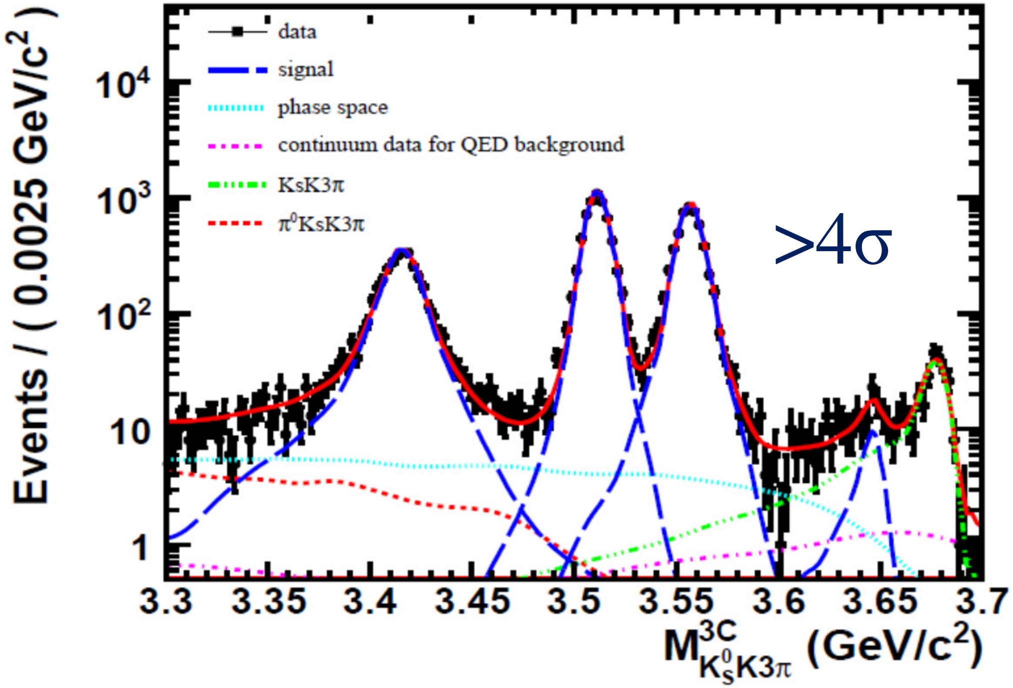
- Better chance to observe $\eta_c(2S)$ in $\psi(2S)$ radiative transition with ~106M $\psi(2S)$ data at BESIII.

- $\psi(2S) \to \gamma\eta_c(2S) \to \gamma K_S K\pi$ / $\gamma K^+K^-\pi^0$ observed (>10σ): PRL109, 042003 (2012).

PRD87, 052005 (2013)

$\psi(2S) \to \gamma\eta_c(2S) \to \gamma K_s K^{+-} \pi^{-+} \pi^{+} \pi^{-}$

- For $\eta_c(2S)$, only two measured decay Brs are available: $K \bar{K} \pi$ and $K^+K^- \pi^+ \pi^- \pi^0$
- $\psi' \to \gamma\eta_c(2S)$: M1 transition
- Search for more $\eta_c(2S)$ decay modes
- To measure the mass, width of $\eta_c(2S)$



The measured M, Γ are consistent with previous BESIII observation (PRL109, 042003).

$M = 3646.9 \pm 1.6 \pm 3.6\ \mathrm{MeV}/c^2$

$\Gamma = 9.2 \pm 4.8 \pm 2.9\ \mathrm{MeV}$

$B(\psi(2S) \to \gamma\eta_c(2S)) \times B(K_s K^{+-} \pi^{-+} \pi^{+} \pi^{-})$
$= (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$

$e^+e^- \to \eta J/\psi$ @4.01GeV

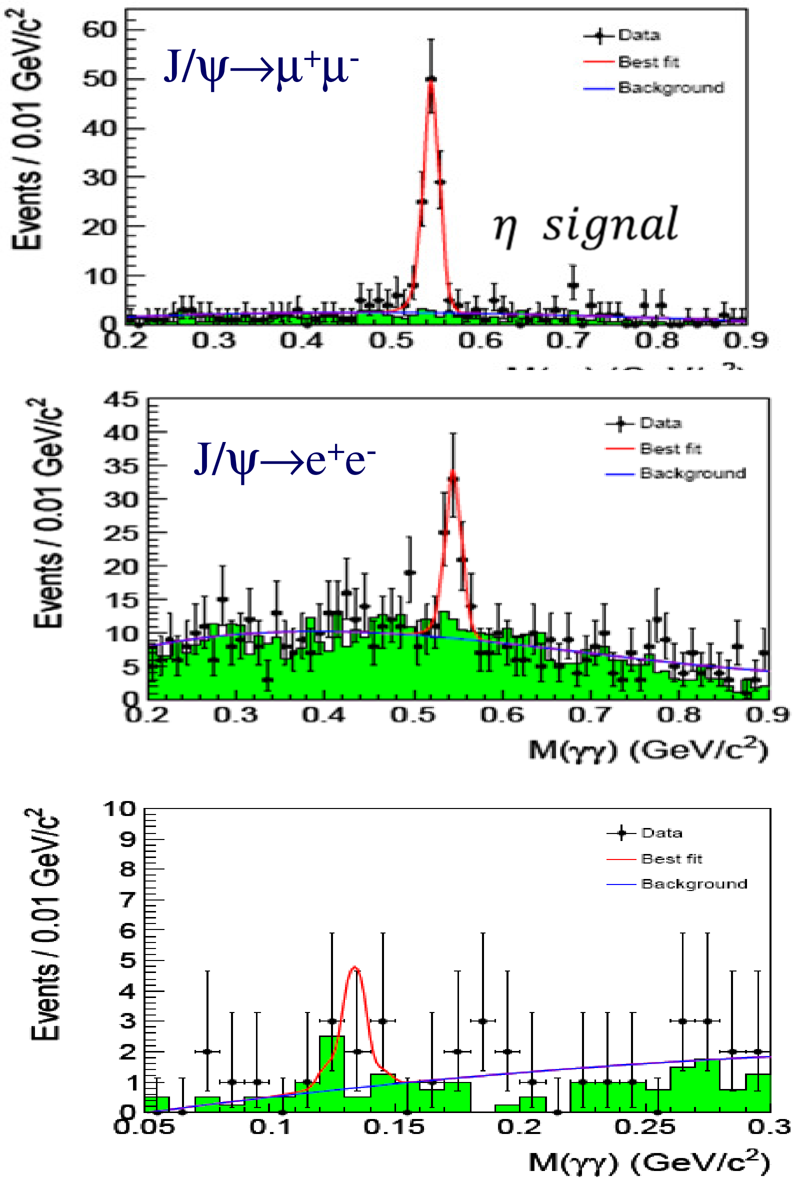
PRD86, 071101(R) (2012)

- **Data sample: 478 pb^{-1} @4.01GeV**
- **First observation: $e^+e^- \to \eta J/\psi$ (significance > 10σ)**
- **Born cross section: (32.1$\pm$2.8 $\pm$1.3) pb**
- **Assuming $\eta J/\psi$ from $\psi(4040)$,**

$Br(\psi(4040)\to\eta J/\psi)=(5.2\pm0.5\pm0.2\pm0.5)\times10^{-3}$

$Br(\psi(4040)\to\pi^0 J/\psi) < 2.8\times10^{-4}$ @90% CL

- **Consistent with the theoretical calculation (Q.Wang et al., arXiv: 1206.4511)**
- **Partial width of $\psi(4040)\to\eta J/\psi$: ~400keV (> two times $\psi(4040)\to\pi\pi J/\psi$)**
  - **Similar to the hadronic transition of Υ(4S) (admixture of a four-quark state in the wave function, M. B. Voloshin, Mod. Phys. Lett. A 26, 773 (2011))**



PRD 86, 092008 (2012)

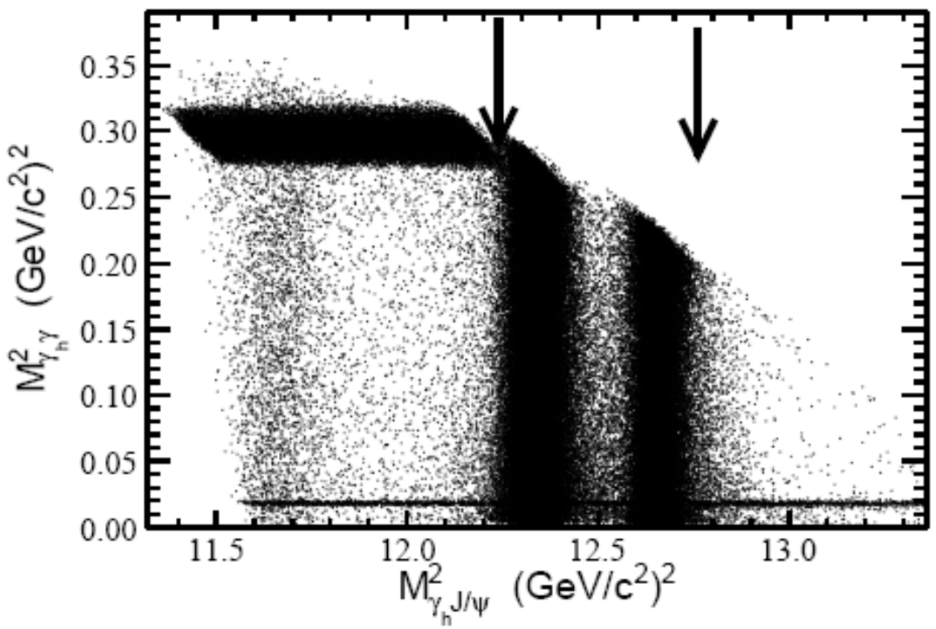
$\psi' \to \eta J/\psi, \pi^0 J/\psi$

- Decay final states: $\gamma\gamma\mu^+\mu^-$ or $\gamma\gamma e^+e^-$
- $\psi' \to \pi^0 J/\psi$ isospin violation
- QCD multipole- expansion + axial anomaly $\Rightarrow$ R = 0.016

(G. A. Miller et al., Phys. Rep. 194, 1 (1990).)

- Charm-meson loops $\Rightarrow$ R = 0.11$\pm$0.06

(F. K. Guo et al., PRL 103, 082003 (2009))



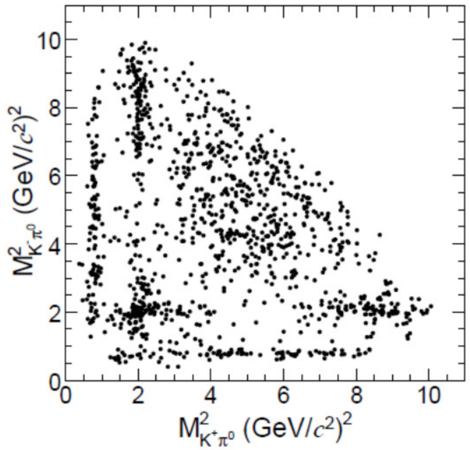
$\mathcal{B}$ or R	Final state	This work	Combined	Particle Data Group review
$\mathcal{B}(\psi' \to \pi^0 J/\psi)$	$\gamma\gamma e^+e^-$	$1.27 \pm 0.03 \pm 0.03$	...	...
$(\times 10^{-3})$	$\gamma\gamma\mu^+\mu^-$	$1.25 \pm 0.03 \pm 0.03$	$1.26 \pm 0.02 \pm 0.03$	1.30 ± 0.10
$\mathcal{B}(\psi' \to \eta J/\psi)$	$\gamma\gamma e^+e^-$	$33.77 \pm 0.23 \pm 0.93$	...	...
$(\times 10^{-3})$	$\gamma\gamma\mu^+\mu^-$	$33.73 \pm 0.24 \pm 0.90$	$33.75 \pm 0.17 \pm 0.86$	32.8 ± 0.7
$R = \frac{\mathcal{B}(\psi' \to \pi^0 J/\psi)}{\mathcal{B}(\psi' \to \eta J/\psi)}$	$\gamma\gamma e^+e^-$	$3.76 \pm 0.09 \pm 0.06$	...	...
$(\times 10^{-2})$	$\gamma\gamma\mu^+\mu^-$	$3.71 \pm 0.09 \pm 0.05$	$3.74 \pm 0.06 \pm 0.04$	3.96 ± 0.42

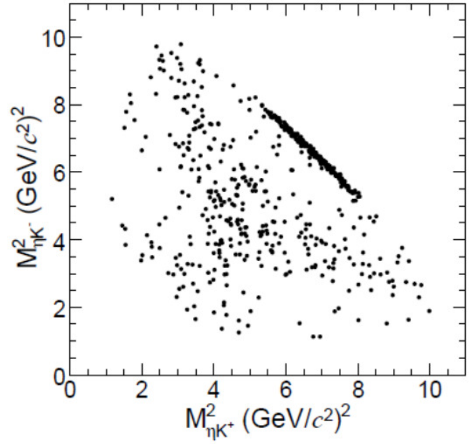
PRD 86, 072011 (2012)

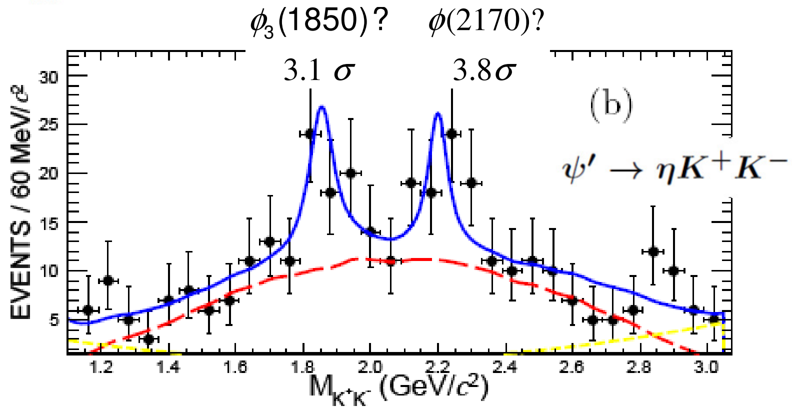
$\psi' \to K^+K^-\pi^0$, $K^+K^-\eta$

- Motivation
  - Test 12% rule (Q_h) & Study $\rho\pi$ puzzle in $\psi' \to$ VP decays
  - Test HSR
  - Search for excited ϕ, K^* states
- PWA applied
  - Measured $\psi' \to KK^*$, $\phi\eta$, $\phi\pi^0$ (isospin violated)
  - Q_h in VP decays significantly deviate from 12%
- First observation: $\psi' \to K^+K^*_2(1430)^-$

(HSR suppressed decay)





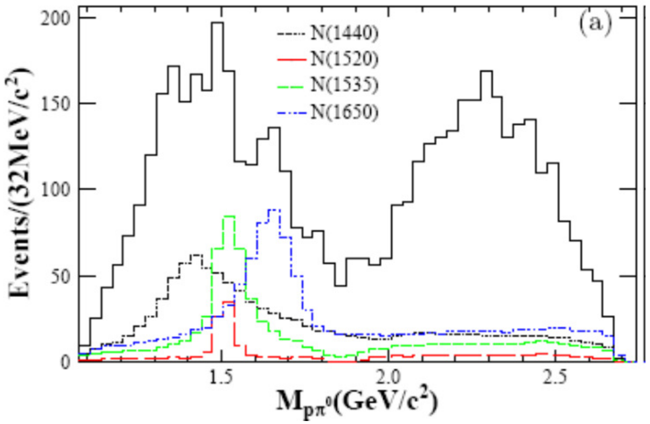


Mode ($\psi' \to$)	ϵ(%)	N^{obs}	$Br(\times 10^{-5})$	Q_h (%)	PDG ($\times 10^{-5}$)	CLEO ($\times 10^{-5}$)	BESII ($\times 10^{-5}$)
$\pi^0 K^+K^-$(inclusive)	21.52	917 ± 37	$4.07 \pm 0.16 \pm 0.26$	...	<8.9 [2]	...	...
$K^*(892)^+K^-$ + c.c.	20.25	224 ± 21	$3.18 \pm 0.30^{+0.26}_{-0.31}$	0.62 ± 0.09	$1.7^{+0.8}_{-0.9}$	$1.3 \pm 1.0 \pm 0.3$	$2.9 \pm 1.3 \pm 0.4$
$K^*_2(1430)^+K^-$ + c.c.	20.28	251 ± 22	$7.12 \pm 0.62^{+1.13}_{-0.61}$	>2	...	...	...
ηK^+K^-($\eta\phi$ excluded)	22.10	284 ± 27	$3.08 \pm 0.29 \pm 0.25$	...	<13	<13	...
$\eta\phi$	33.53	216 ± 16	$3.14 \pm 0.23 \pm 0.23$	4.19 ± 0.61	$2.8^{+1.0}_{-0.8}$	$2.0 \pm 1.1 \pm 0.4$	$3.3 \pm 1.1 \pm 0.5$
$\pi^0\phi$	35.63	<10	<0.04	...	<0.4	0.7	0.4

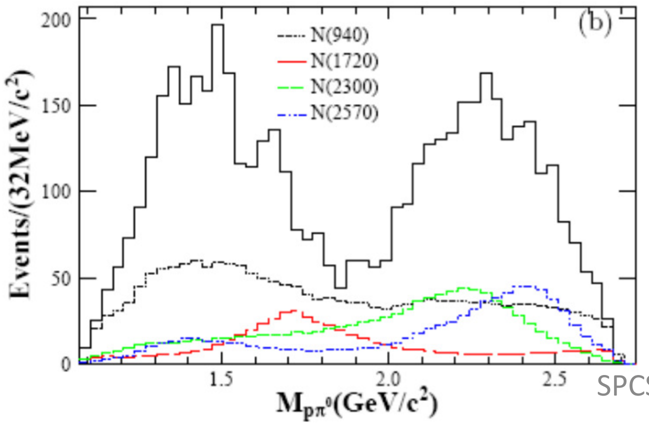
PRL110, 022001 (2013)

PWA of $\psi' \rightarrow p\,\bar{p}\,\pi^0$

- Non-relativistic quark model is successful in interpreting of the excited baryons
- Predicted more excited stated ("missing resonance problem")
- J/ψ (ψ') decays offers an window to search for the missing resonance
- Isospin conservation $\Rightarrow \Delta$ supressed
- Two new baryonic excited states are observed!



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	ΔS	ΔN_{dof}	C.L.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94\ \ -44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ



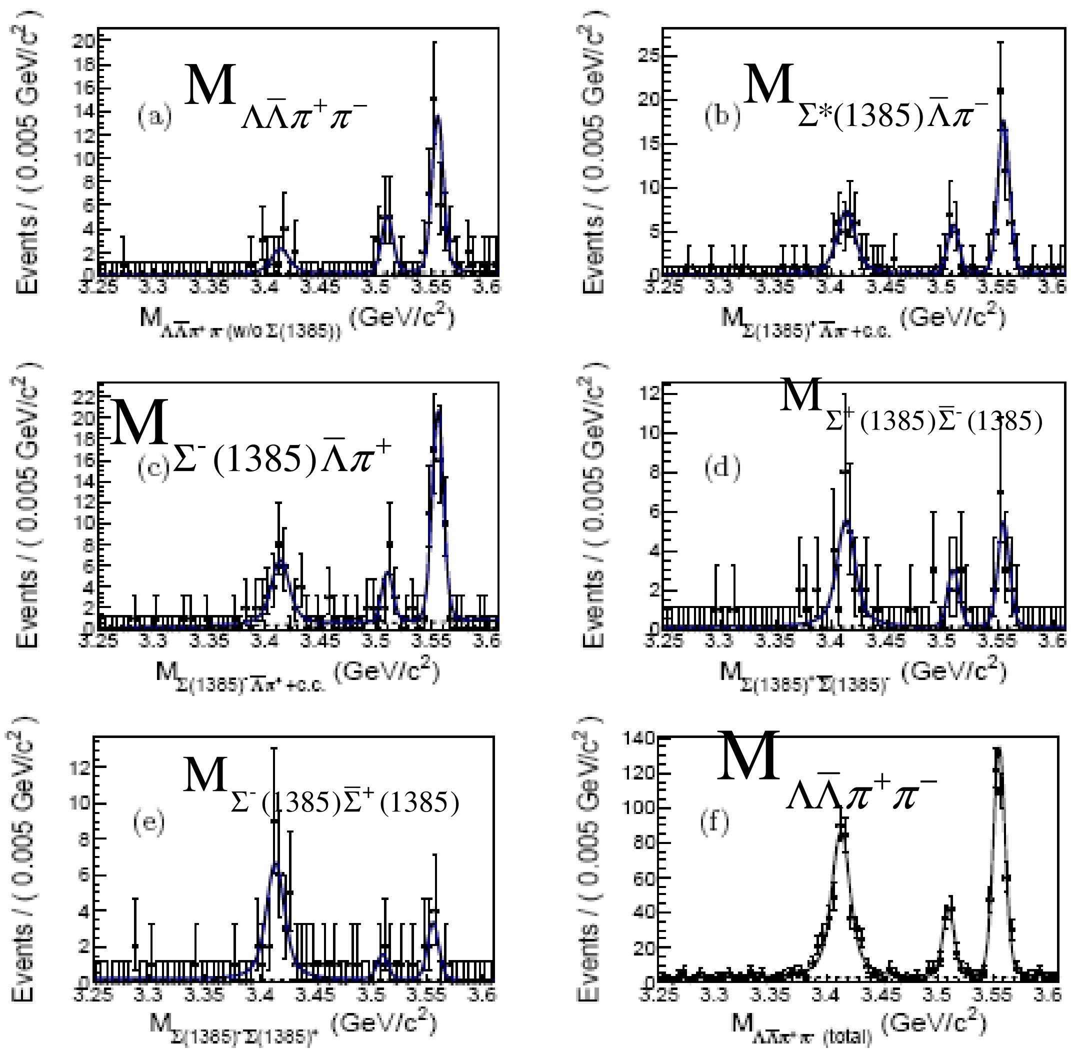
Resonance	N	$\epsilon(\%)$	B.F.$(\times 10^{-5})$
$N(940)$	$1870^{+90+487}_{-90-327}$	27.2 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.6 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	27.7 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	25.5 ± 0.4	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	26.9 ± 0.4	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	26.6 ± 0.4	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	33.8 ± 0.4	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	34.9 ± 0.4	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	4515 ± 93	25.5 ± 0.4	$16.5 \pm 0.3 \pm 1.5$

PRD 86, 052004 (2012)

$\chi_{cJ} \to \Lambda \bar{\Lambda} \pi^+ \pi^-$

- Color-Octet contribution: Large effect in P-wave state.
  - e.g. : $\chi_{cJ} \to p \bar{p}$, theoretical prediction consistent with exp.

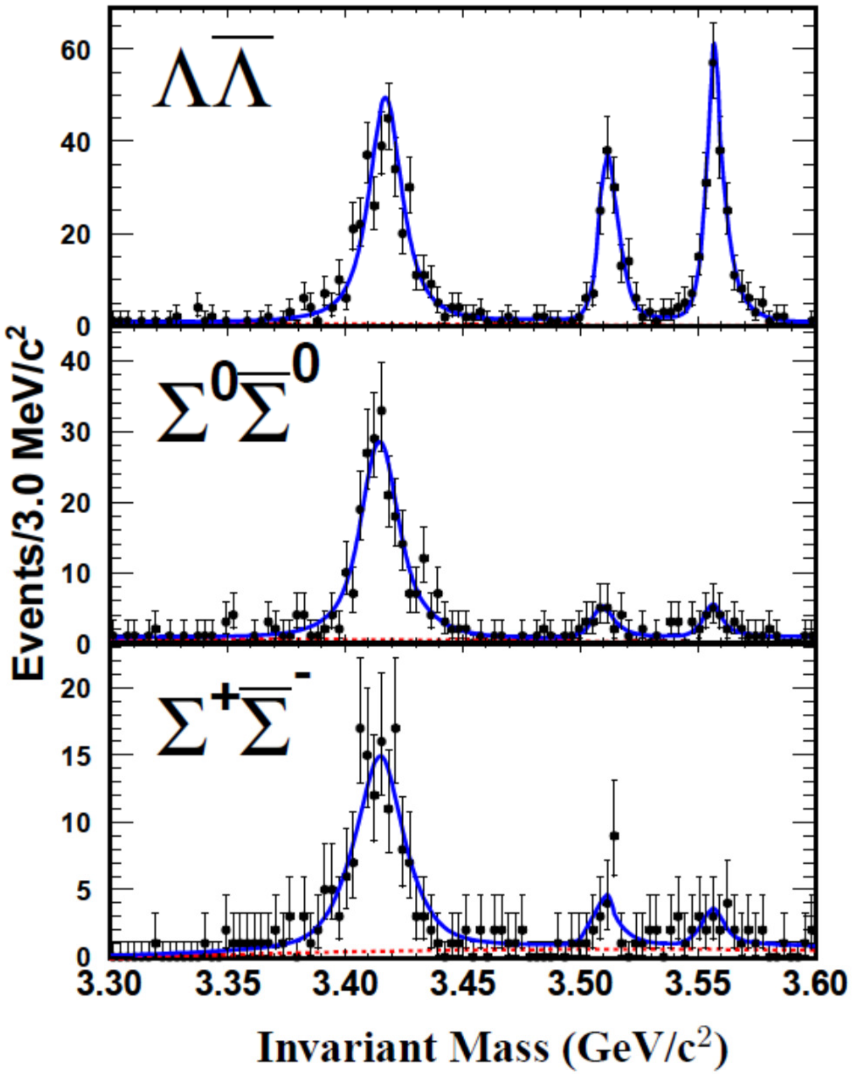
    (Wong, Nucl. Phys. A674, 185 (2000))
  - $\chi_{cJ} \to \Lambda \bar{\Lambda}$ not consistent
  - What about other baryon anti-baryon decays?
- Experiment measured
  - NR: $\chi_{cJ} \to \Lambda \bar{\Lambda} \pi^+ \pi^-$
  - $\chi_{cJ} \to \Sigma(1385)^+ \bar{\Lambda} \pi^-$ +cc
  - $\chi_{cJ} \to \Sigma(1385)^- \bar{\Lambda} \pi^+$ +cc
  - First evidence: $\chi_{cJ} \to \Sigma(1385) \bar{\Sigma}(1385)$
  - Experiment consist with theoretical prediction



PRD 87, 032007 (2013)

$\chi_{cJ} \rightarrow \Lambda\,\bar{\Lambda},\ \Sigma^0\,\bar{\Sigma}^0,\ \Sigma^+\,\bar{\Sigma}^-$

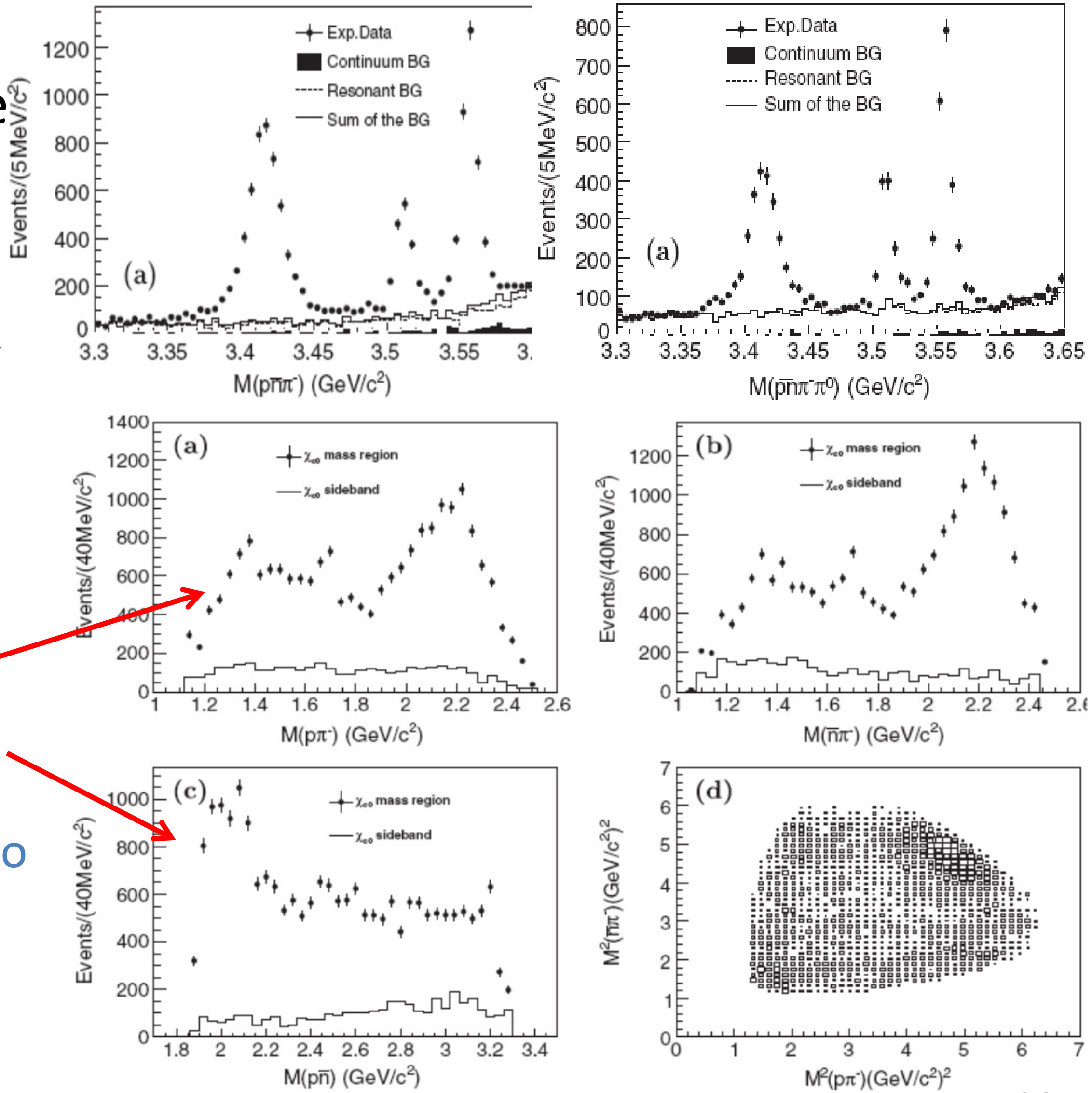
- χ_{cJ} decay properties are essential to test pQCD models and QCD-based calculations.
- many decay modes of $\chi_{cJ} \rightarrow B\bar{B}$ have not been observed yet, or measured with poor precision.
- measurements of $\chi_{cJ} \rightarrow B\bar{B}$ are helpful for understanding the HSR, which prohibits χ_{c0} decays into baryon-antibaryon pairs.



PRD 86, 052011 (2012)

$\chi_{cJ} \to p\,\bar{n}\,\pi^-$, $p\,\bar{n}\,\pi^-\pi^0$

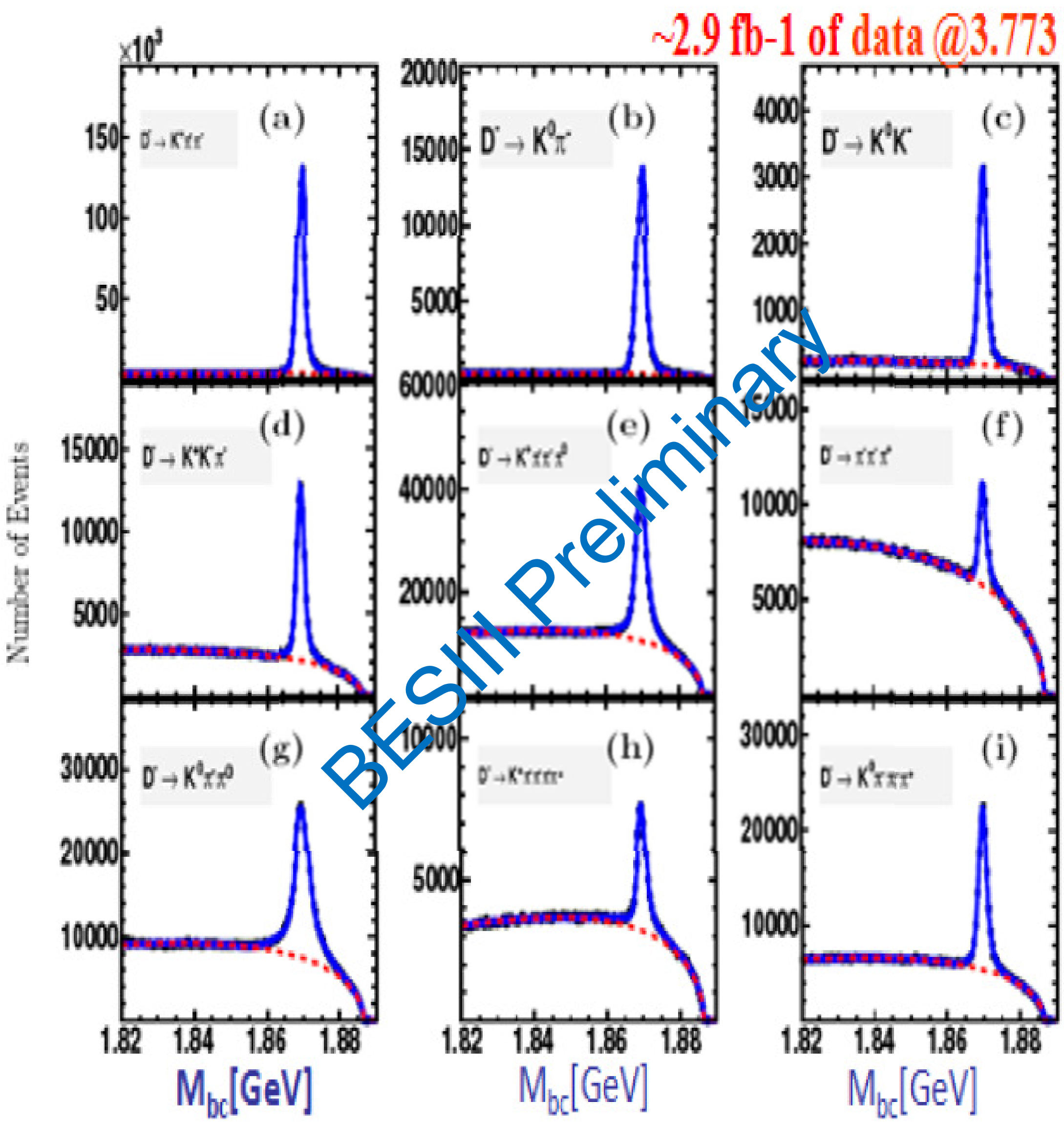
- Color-Octet contribution: Large effect in P-wave state
- Search for N* states
- Experiment measured
  - Branching fractions for $\chi_{c0,1,2} \to p\,\bar{n}\,\pi^-$ +c.c.
    $\chi_{c0,1,2} \to p\,\bar{n}\,\pi^-\pi^0$ +c.c.
    (most precise measurements)
- Intermediate states:
  - N*(1400), N*(1700) in both $p\pi$ and $\bar{n}\,\pi$
  - Threshold enhancement of $p\bar{n}$, or N*(2190), N*(2220)?
  - Further detailed PWA need to be done!

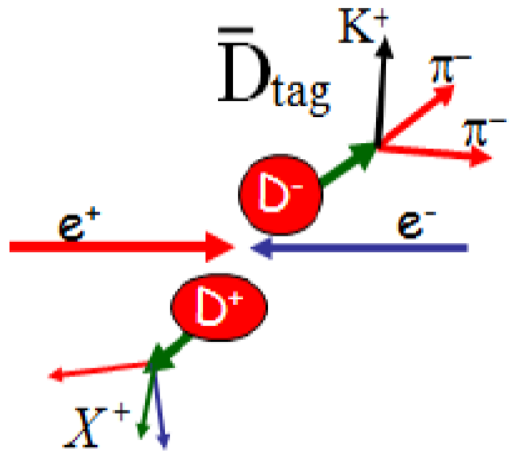


Charm Physics (all preliminary)

- **$D^+ \to \mu^+ \nu$**
- $D^0 \to K^- / \pi^- e^+ \nu$
- Search for $D^0 \to \gamma\gamma$
- Ds tagging

D⁻ Tagging





$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

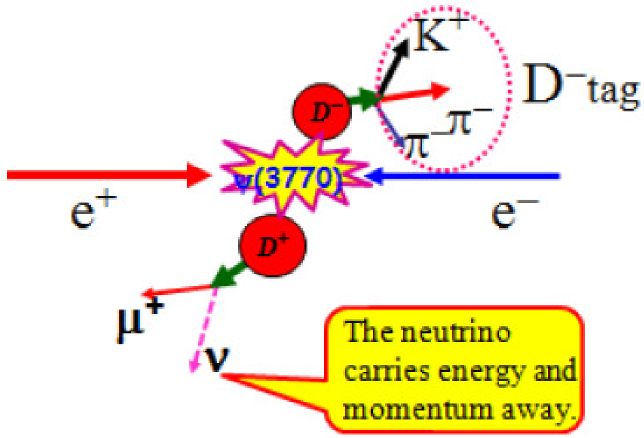
Resolution:
1.3 MeV for pure charged modes;
1.9 MeV for modes with one π^0.

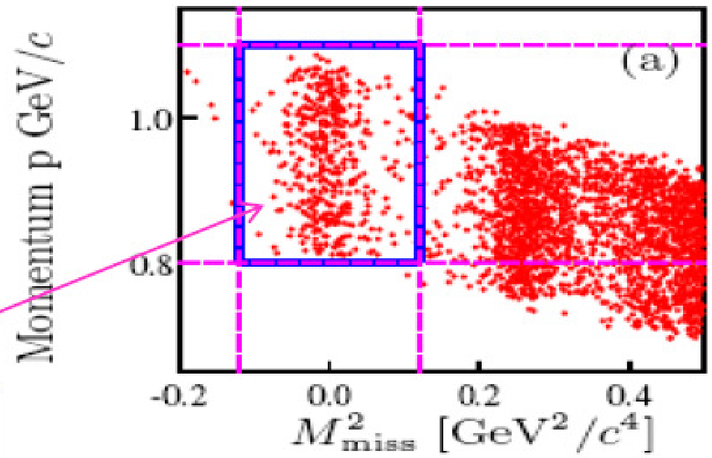
9 singly tagged modes

$N_{D^-} = (1.57 \pm 0.2) \times 10^6$

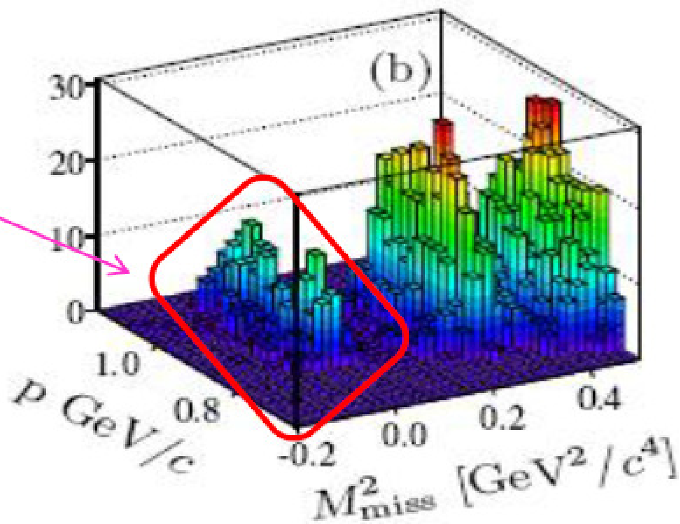
$D^+ \to \mu^+\nu$

- **In the system recoiling against the tagged D^-, select leptonic decay for $D^+ \to \mu^+\nu$**





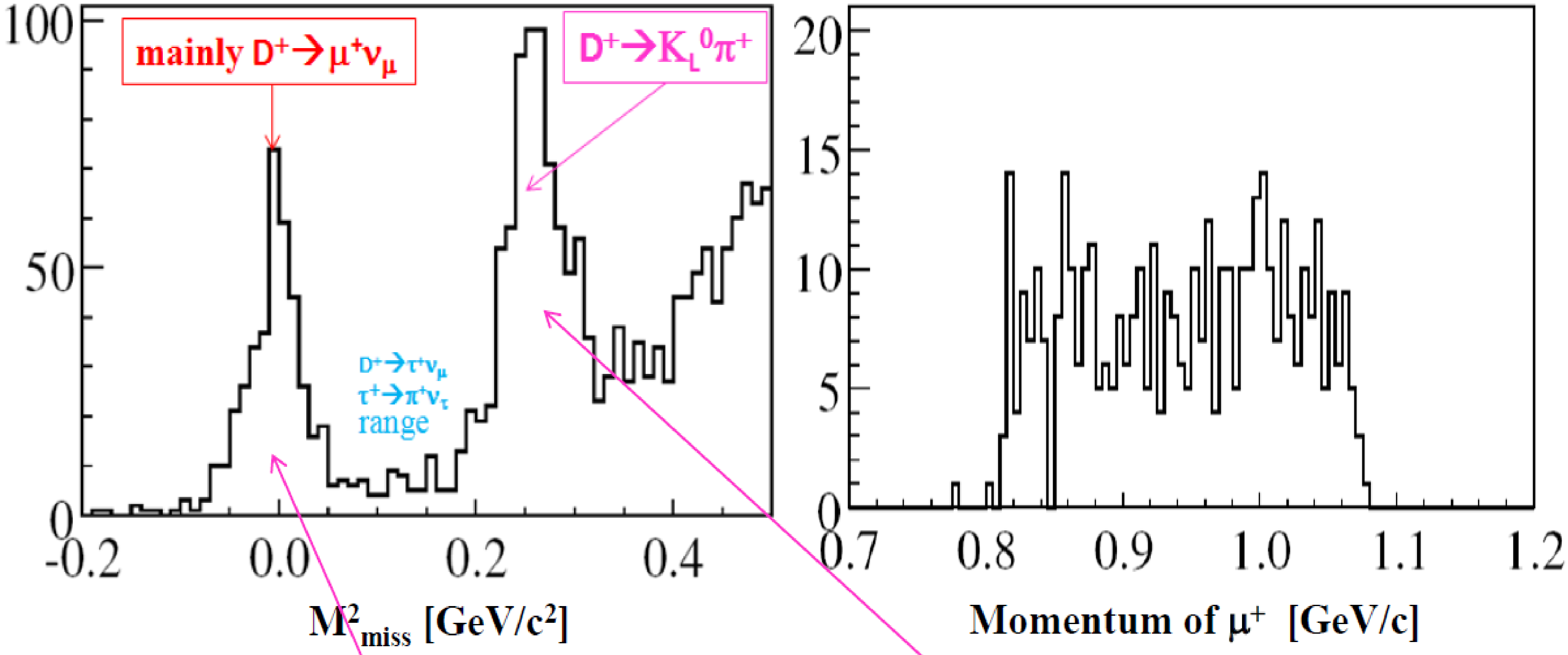
425 candidates for $D^+ \to \mu^+\nu$



Signal selection:

- **One charged track only**
- **Positively identified μ**
- **No isolate photon**

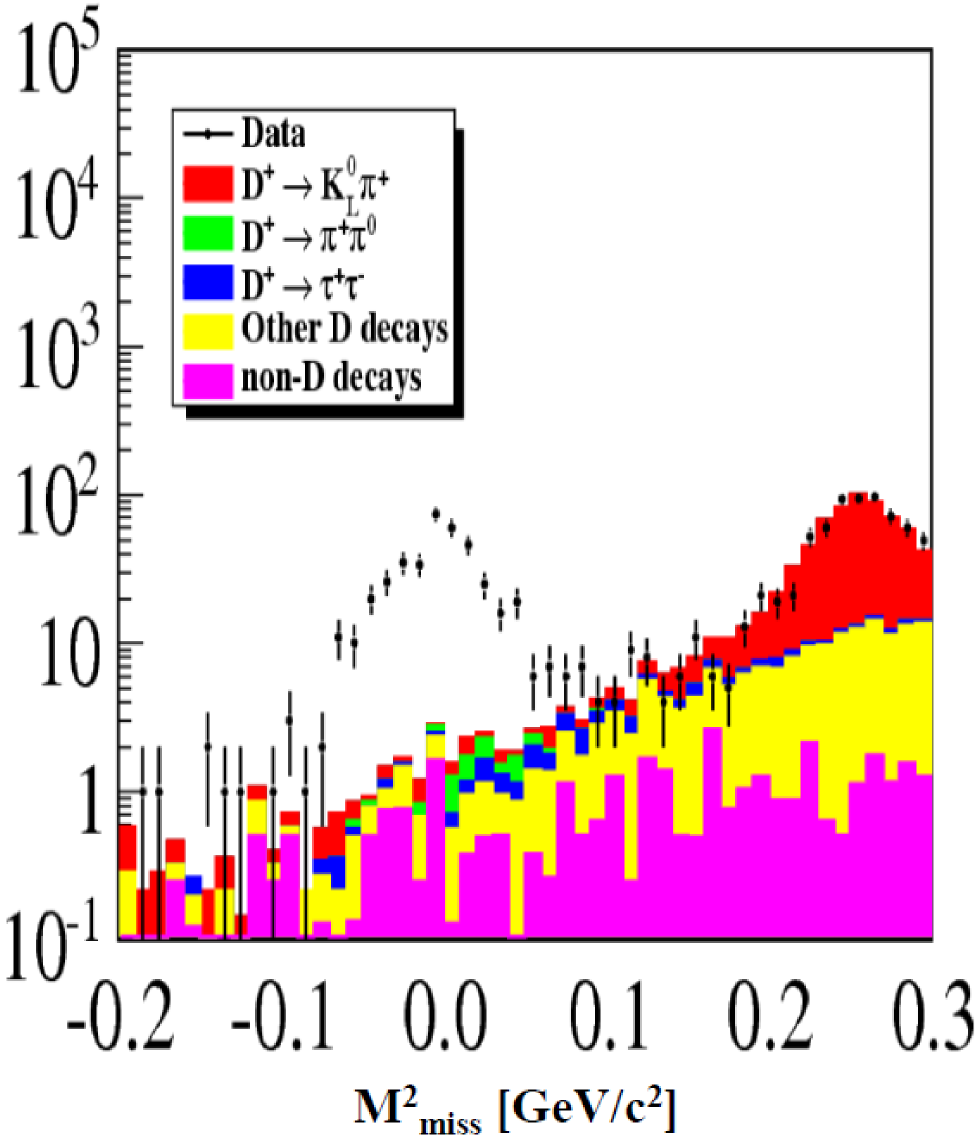
$D^+ \to \mu^+ \nu$



The K^0_L escape from the detector.

There are still some backgrounds

Backgrounds for $D^+ \rightarrow \mu^+\nu$



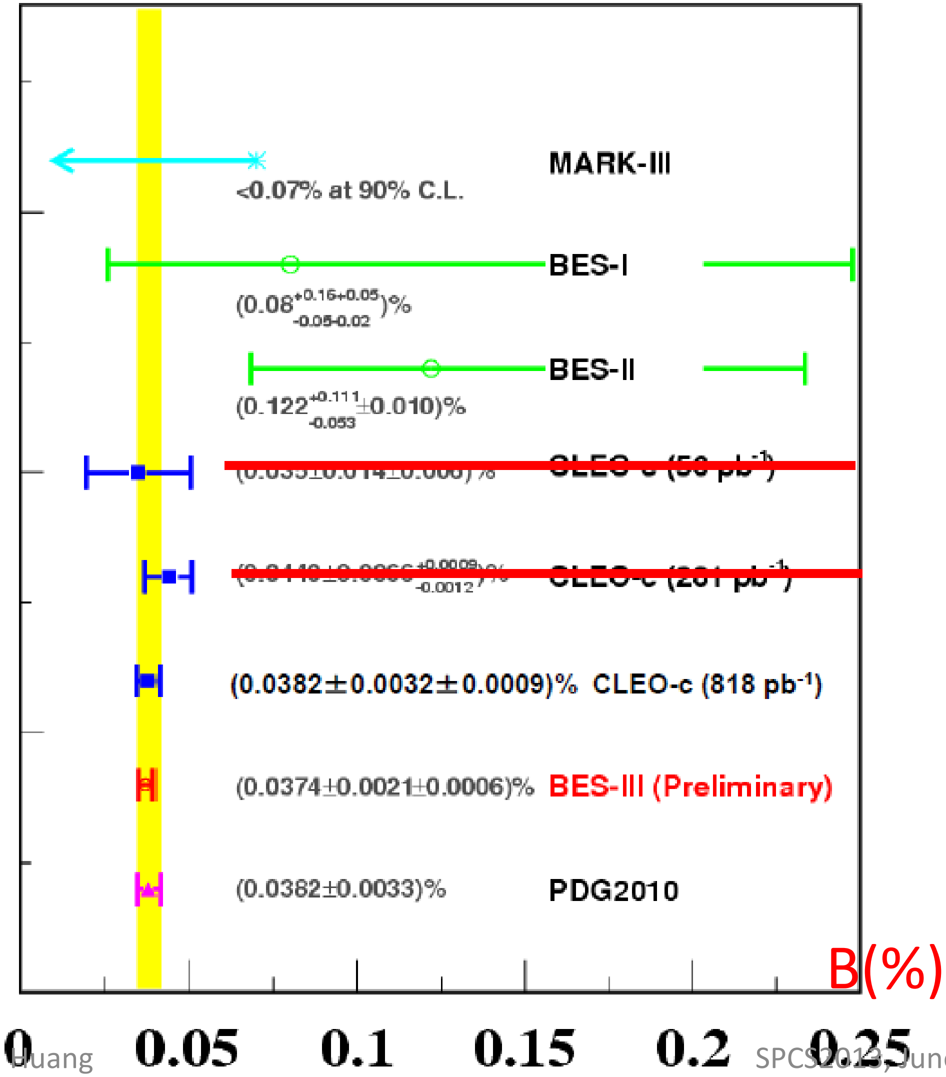
Estimated with Monte Carlo events

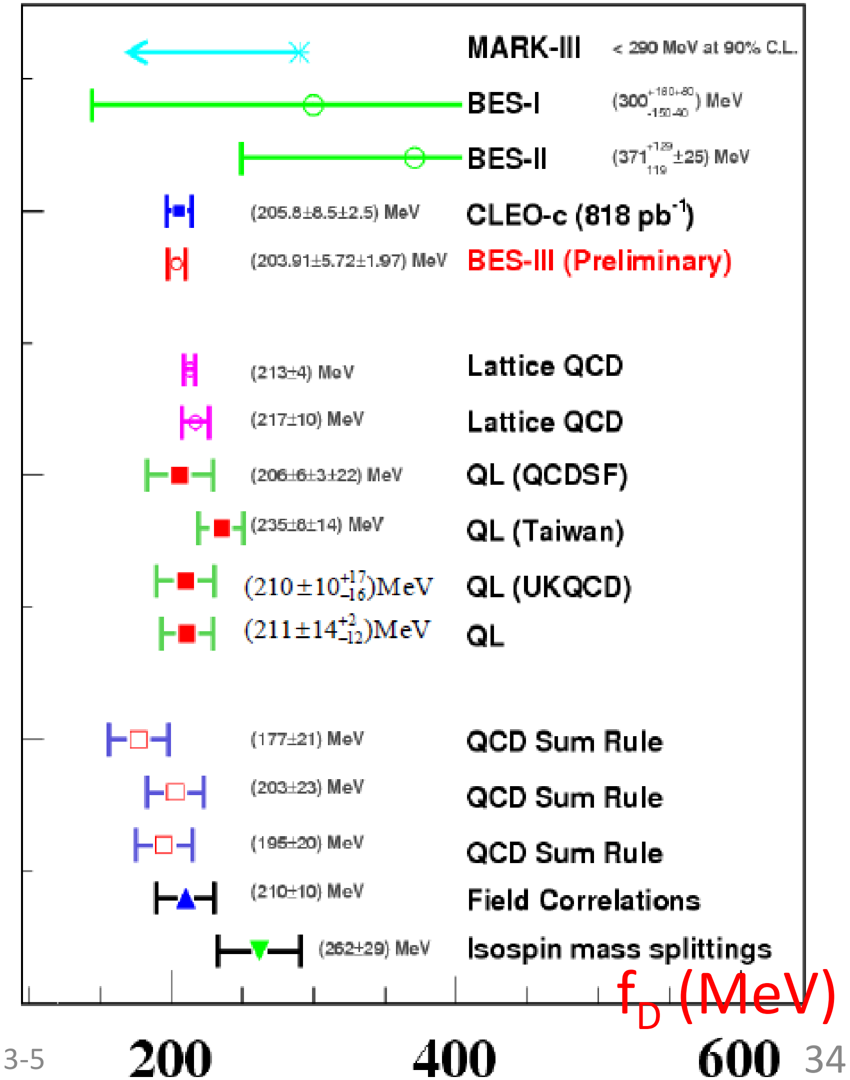
Source mode	Number of events
$D^+ \rightarrow K_L^0\pi^+$	7.9 ± 0.8
$D^+ \rightarrow \pi^+\pi^0$	3.8 ± 0.5
$D^+ \rightarrow \tau^+\nu_\tau$	6.9 ± 0.7
Other decays of D mesons	17.9 ± 1.1
$e^+e^- \rightarrow \gamma\psi(3686)$	0.2 ± 0.2
$e^+e^- \rightarrow \gamma J/\psi$	0.0 ± 0.0
$e^+e^- \rightarrow$ *light hadron* (continuum)	8.2 ± 1.4
$e^+e^- \rightarrow \tau^+\tau^-$	1.9 ± 0.5
$\psi(3770) \rightarrow non - D\bar{D}$	0.9 ± 0.4
Total	47.7 ± 2.3

$D^+ \to \mu^+ \nu$: Preliminary Results

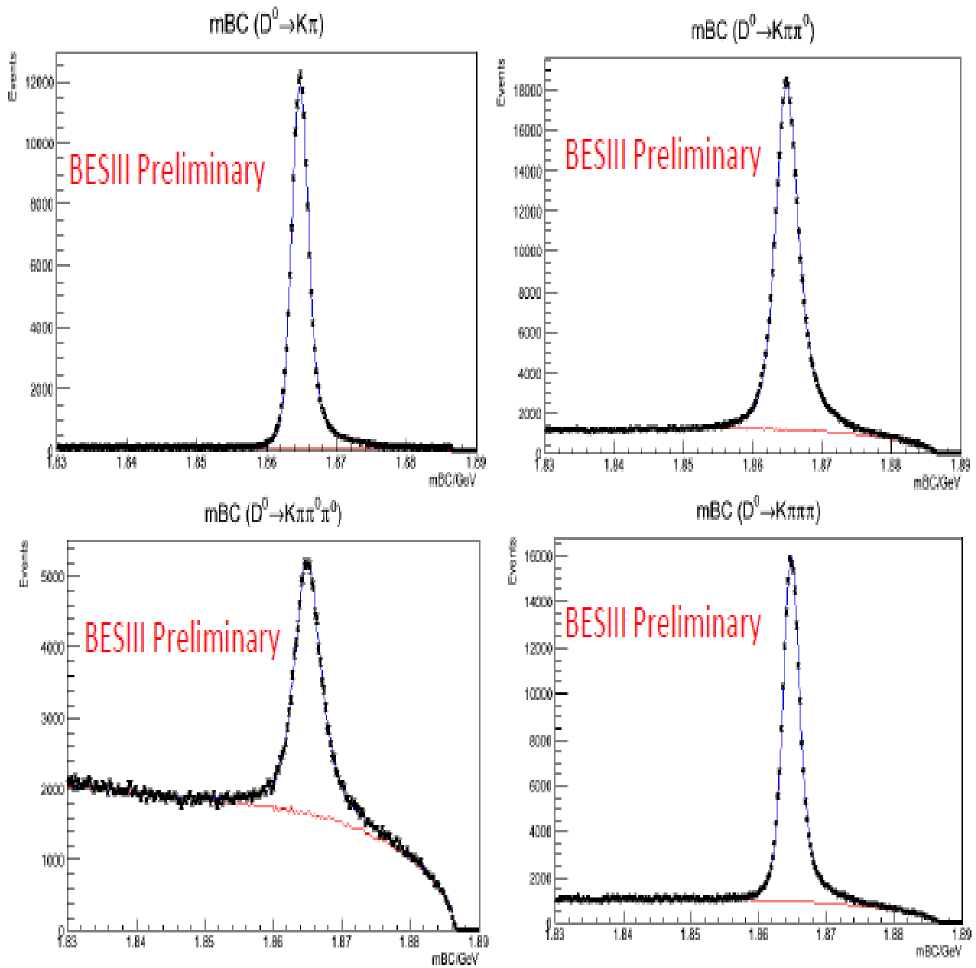
N($D^+ \to \mu^+ \nu$) = 377.3 ± 20.6

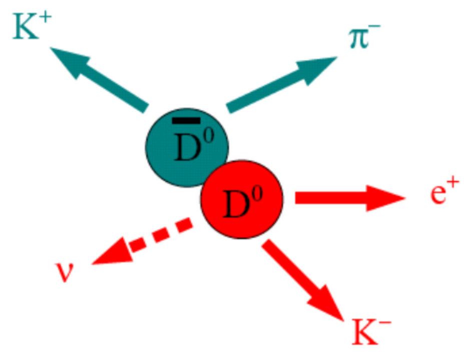
B($D^+ \to \mu^+ \nu$) = (3.74 ± 0.21^{stat} ± 0.06^{sys})x10^{-4} **f**$_D^+$ = (203.91 ± 5.72^{stat} ± 1.97^{sys}) MeV





D^0 Tagging

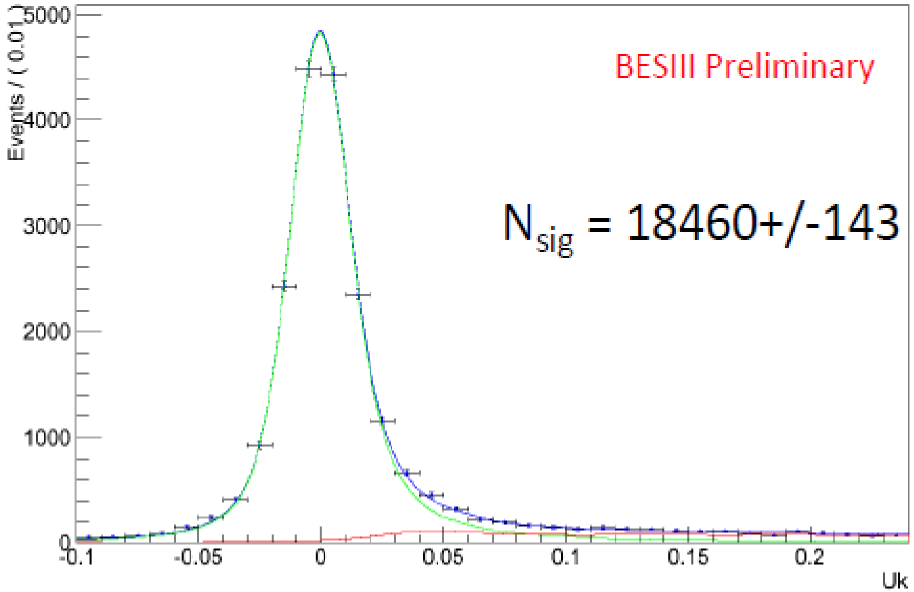




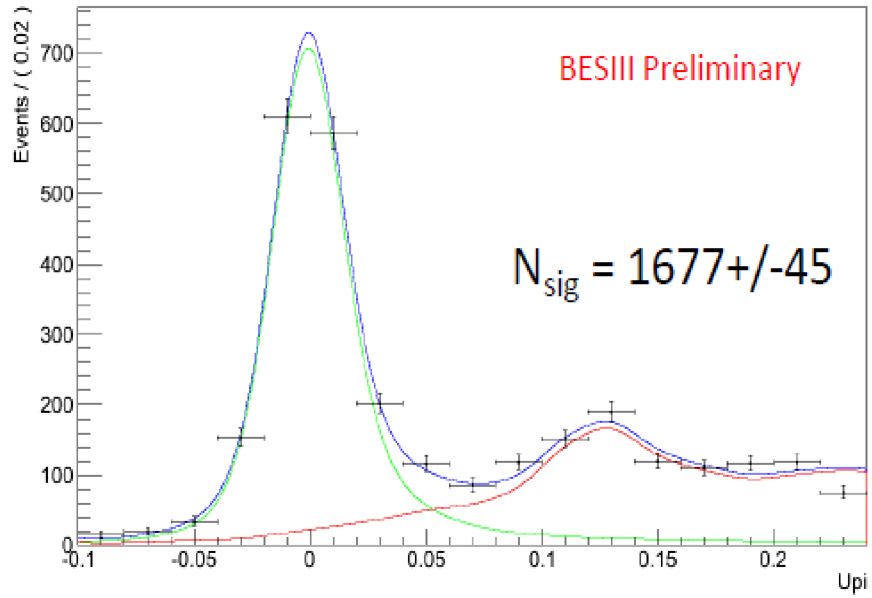
4 tag modes, 0.92 fb^{-1} data @3.773 (preliminary)

Mode	Data Yield
$D^0 \to K^-\pi^+$	159,929 ± 413
$D^0 \to K^-\pi^+\pi^0$	323,348 ± 667
$D^0 \to K^-\pi^+\pi^0\pi^0$	78,467 ± 480
$D^0 \to K^-\pi^+\pi^-\pi^+$	211,910 ± 550

$D^0 \to K/\pi\, e\, \nu$



D^0 -> K e ν



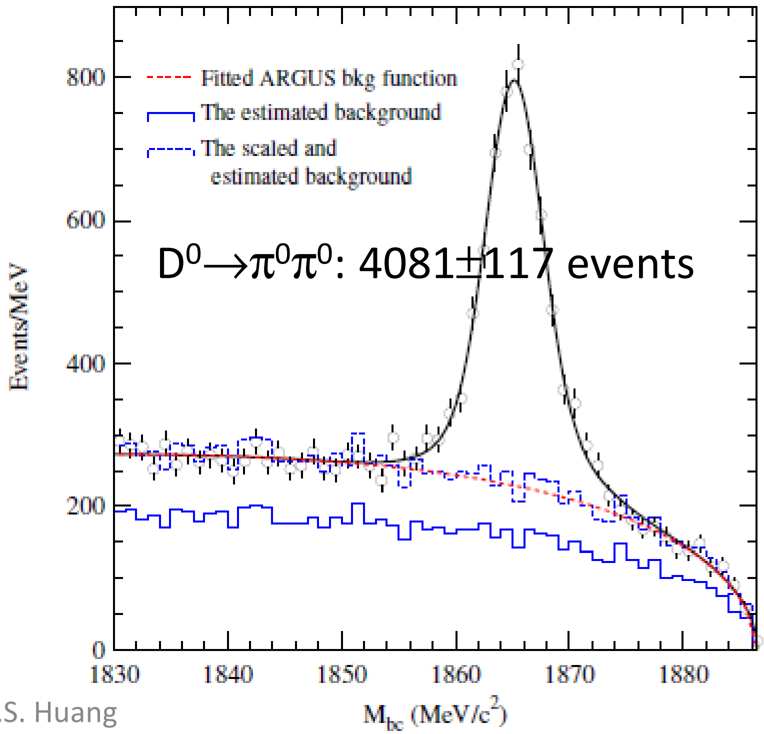
D^0 -> π e ν

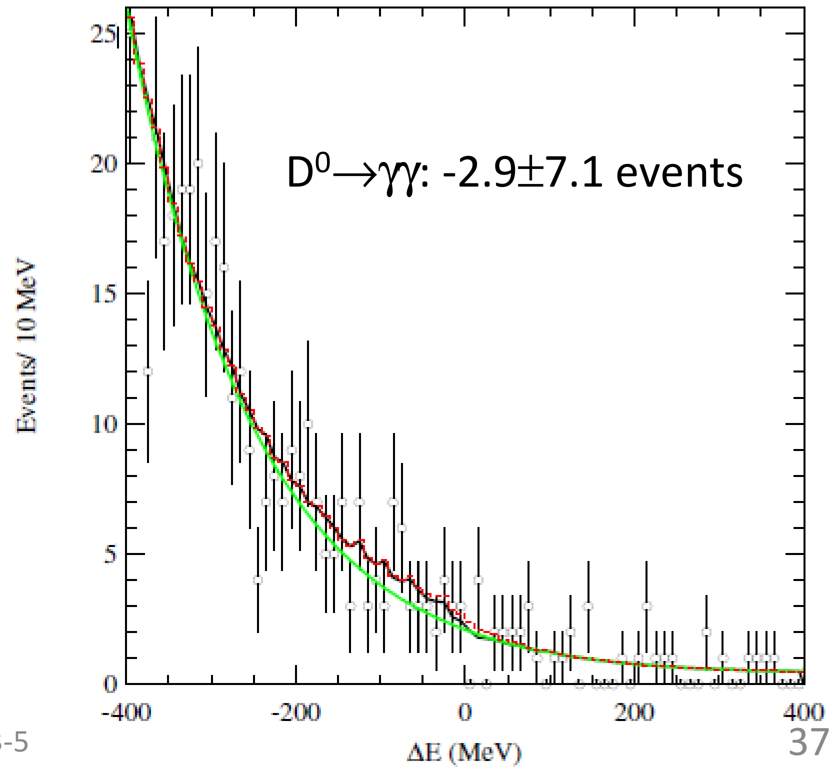
Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

BESIII preliminary, with 0.92 fb^{-1} data, will improve with full 2.9 fb^{-1} soon. Form factor measurement ongoing.

Search for $D^0 \to \gamma\gamma$

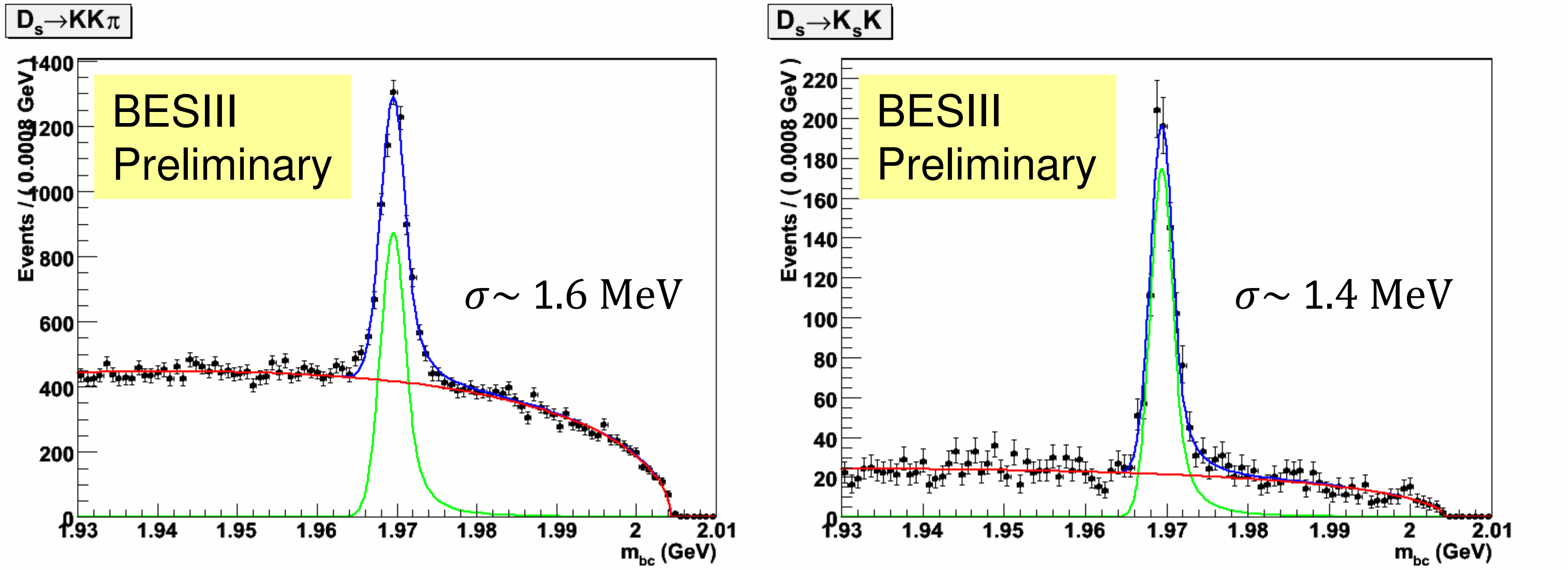
- Forbidden FCNC transition ($c \to u+\gamma$);
- SM prediction: $B(D^0 \to \gamma\gamma) \sim 10^{-8}$ or less;
- Results presented in $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$ UL @ 90% CL, or $B(D^0 \to \gamma\gamma) < 4.6 \times 10^{-6}$ UL @ 90% CL (preliminary, to be improved);
- PDG 2.7×10^{-5}, CLEO-c preli. 8.63×10^{-6}, BaBar 2.2×10^{-6}.





D_s Tag

(part of data @ 4010 MeV)



f_{Ds} (both μ and τ modes) measurement underway

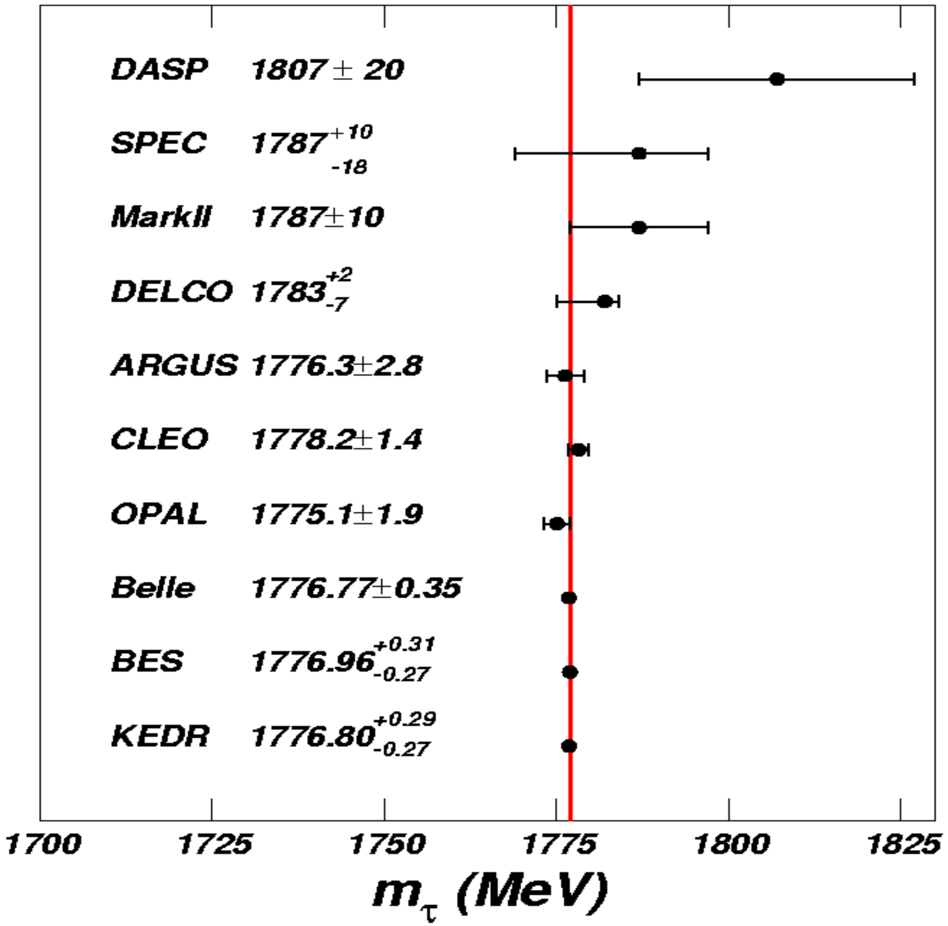
Note: this data is at 4010 MeV: $\sim$0.3 nb of $D_S^+ D_S^-$

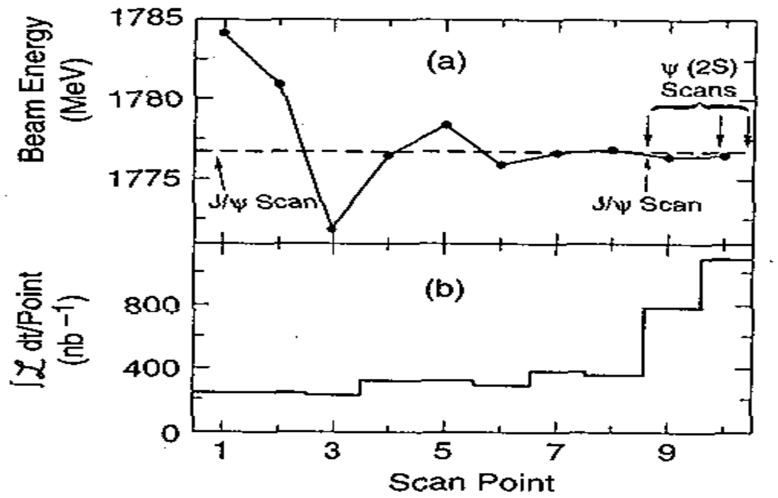
We plan to run at 4170 MeV: $\sim$0.9 nb of $D_S^{*+} D_S^-$

pro: higher cross-section; **con**: need D_S^* transition photon ($D_S^{*+} \to \gamma D_S^+$)

τ Mass Scan

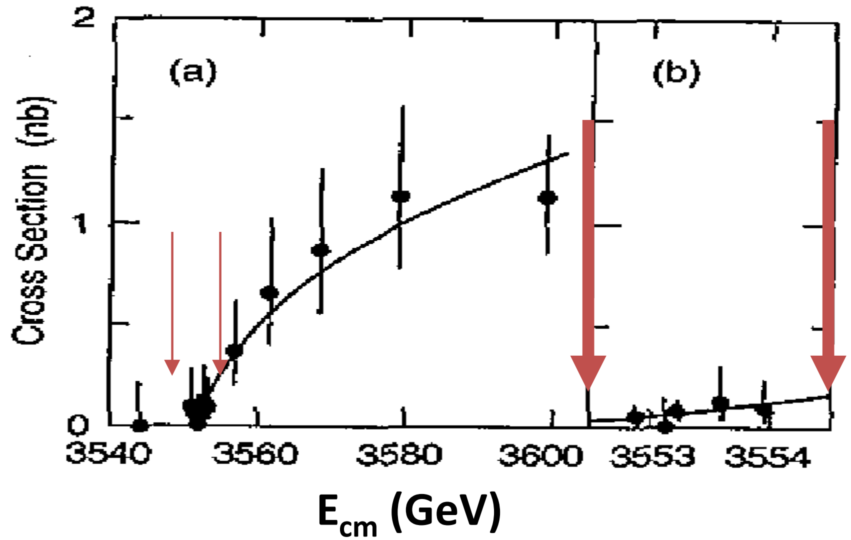
τ Mass measurement





PRD 53 (1993)20

12 points, Lum.: 5 pb^{-1}



$$M_\tau = 1776.96 {}^{+0.18}_{-0.21} {}^{+0.25}_{-0.17} \text{ MeV}$$

$$\sigma M_\tau / M_\tau = 1.7 \times 10^{-4}$$

PDG10: 1776.82±0.16 MeV

BESI results: stat. err. (0.18 / 0.21) is compatible with syst. (0.25 / 0.17)

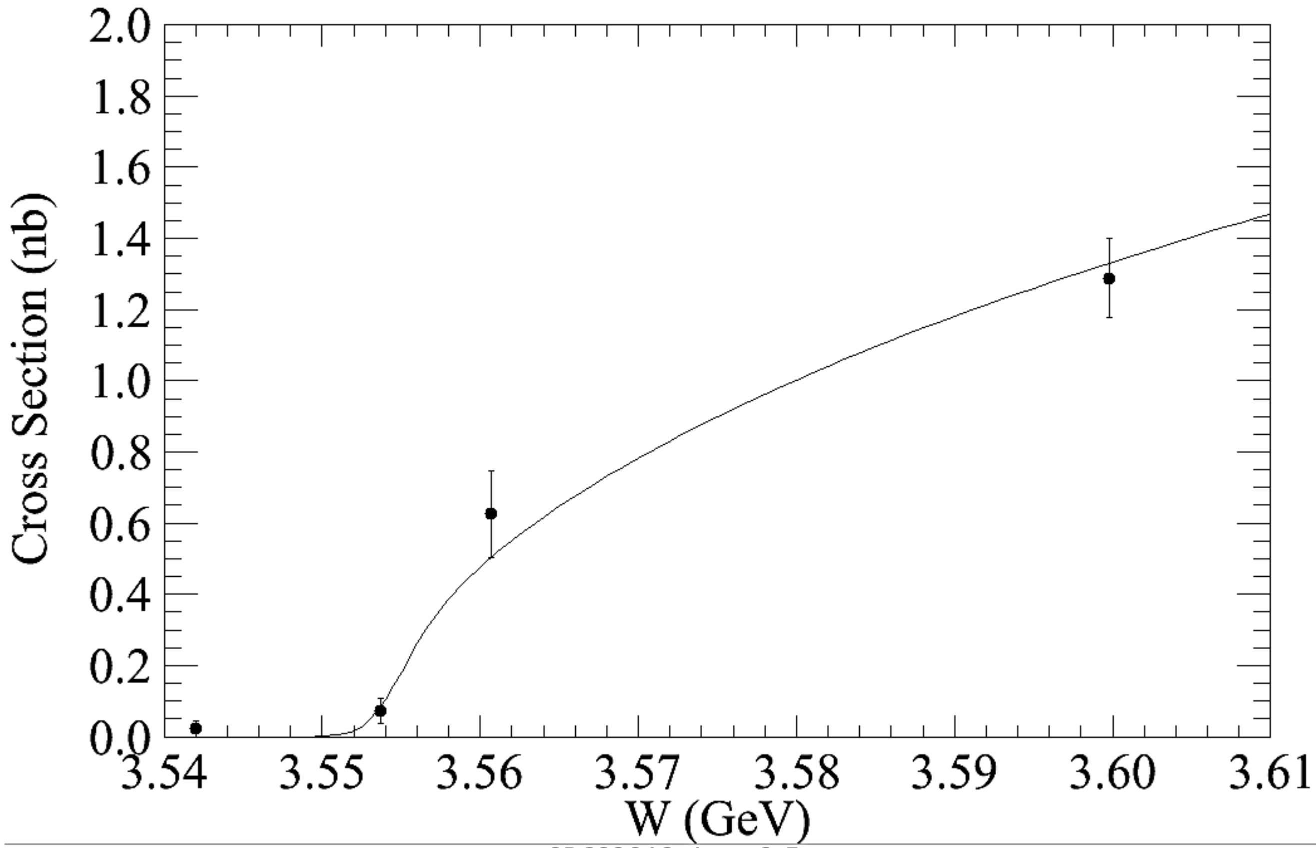
τ Mass measurement in 2012

New beam energy measurement system with a precision of 5×10^{-5};

Data at 4 energy points were taken, ~5 pb^{-1} at the τ threshold;

Expect statistical precision is ±0.3 MeV, systematic error <0.1 MeV;

More data expected later to reduce statistical precision to 0.1 MeV.



Summary

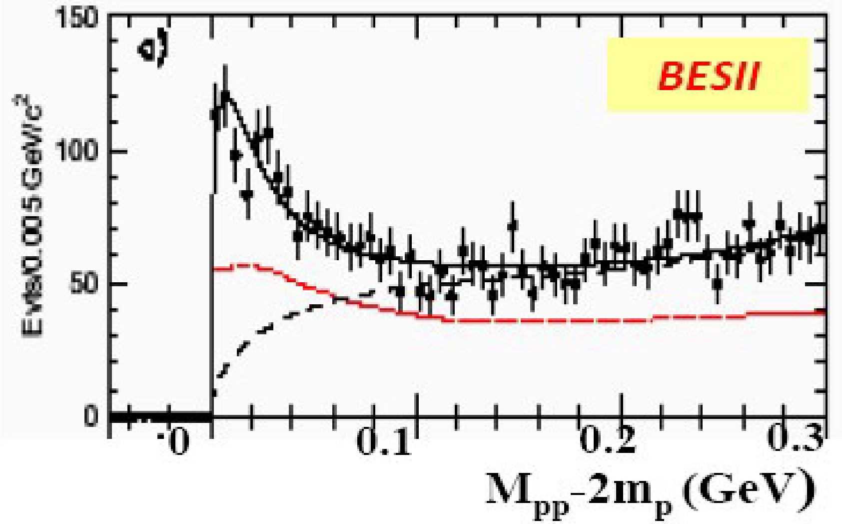
- BESIII has been successfully operating since 2008:
  - World largest data samples at J/ψ, $\psi(2S)$, $\psi(3770)$, $Y(4260)$, $Y(4360)$, …
- Study of XYZ mesons:
  - Observation of the Zc(3900).
- Light quark states:
  - $\omega\phi$ threshold enhancement in $J/\psi\to\gamma\omega\phi$.
  - $\eta\eta$ system in $J/\psi\to\gamma\eta\eta$.
  - $J/\psi\to\Lambda\,\bar{\Sigma}^0$ + c.c.
- Charmonium transitions and decays:
  - Observation of $\eta_c(2S)$ in $\psi(2S)\to\gamma\eta_c(2S)$ decay.
  - $e^+e^-\to\eta\, J/\psi$ @4.009 GeV.
  - $\psi(2S)\to\eta J/\psi$, $\pi^0 J/\psi$, $\psi(2S)\to K^+K^-\pi^0$, $K^+K^-\eta$
  - New states in $\psi(2S)\to p\,\bar{p}\,\pi^0$
  - $\chi_{cJ}\to\Lambda\,\bar{\Lambda}\,\pi^+\,\pi^-$, $\chi_{cJ}\to\Lambda\,\bar{\Lambda}$, $\Sigma^0\,\bar{\Sigma}^0$, $\Sigma^+\,\bar{\Sigma}^-$, $\chi_{cJ}\to p\,\bar{n}\,\pi^-$, $p\,\bar{n}\,\pi^-\,\pi^0$
- Charm decays:
  - $D^+\to\mu^+\nu$, $D^0\to K/\pi\, e\,\nu$, $D^0\to\gamma\gamma$.
- τ mass measurement.
- **Lots of results published, more to come!**

Recent Results on Light Hadron Physics

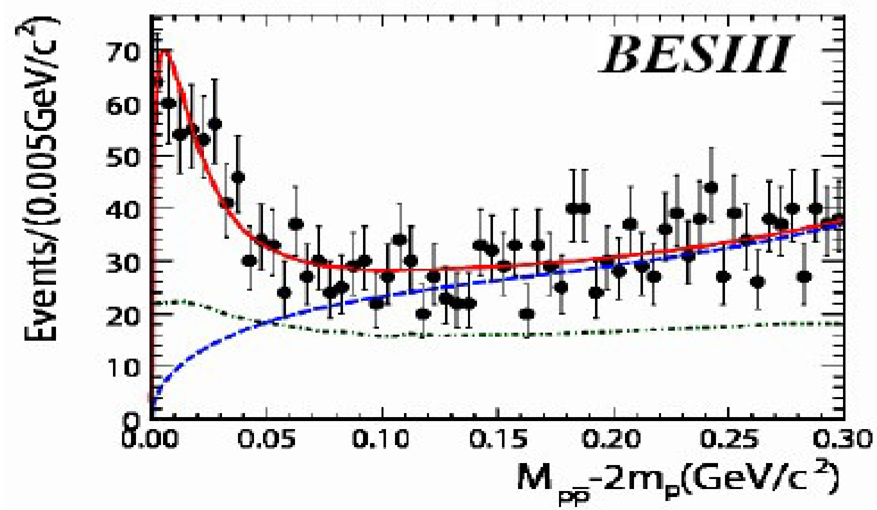
- **$p\bar{p}$ mass threshold structure in $J/\psi \to \gamma p\bar{p}$**
- $\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to 2\pi$
- 3π Decays of J/ψ and $\psi(2S)$

Enhancement at $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$

$J/\psi \to \gamma p\bar{p}$



$\psi' \to \pi^+\pi^- J/\psi,\ J/\psi \to \gamma p\bar{p}$



Observed at BESII in 2003 (PRL,022001)
agree with spin zero expectation
M $=1860^{+3}_{-10}{}^{+5}_{-25}$ MeV, Γ< 38 MeV (90% CL)

Confirmed at BESIII in 2010
(CPC 34,421 (2010))
M $=1859^{+6}_{-13}{}^{+6}_{-26}$ MeV, Γ< 30 MeV (90% CL)

Many possibilities:

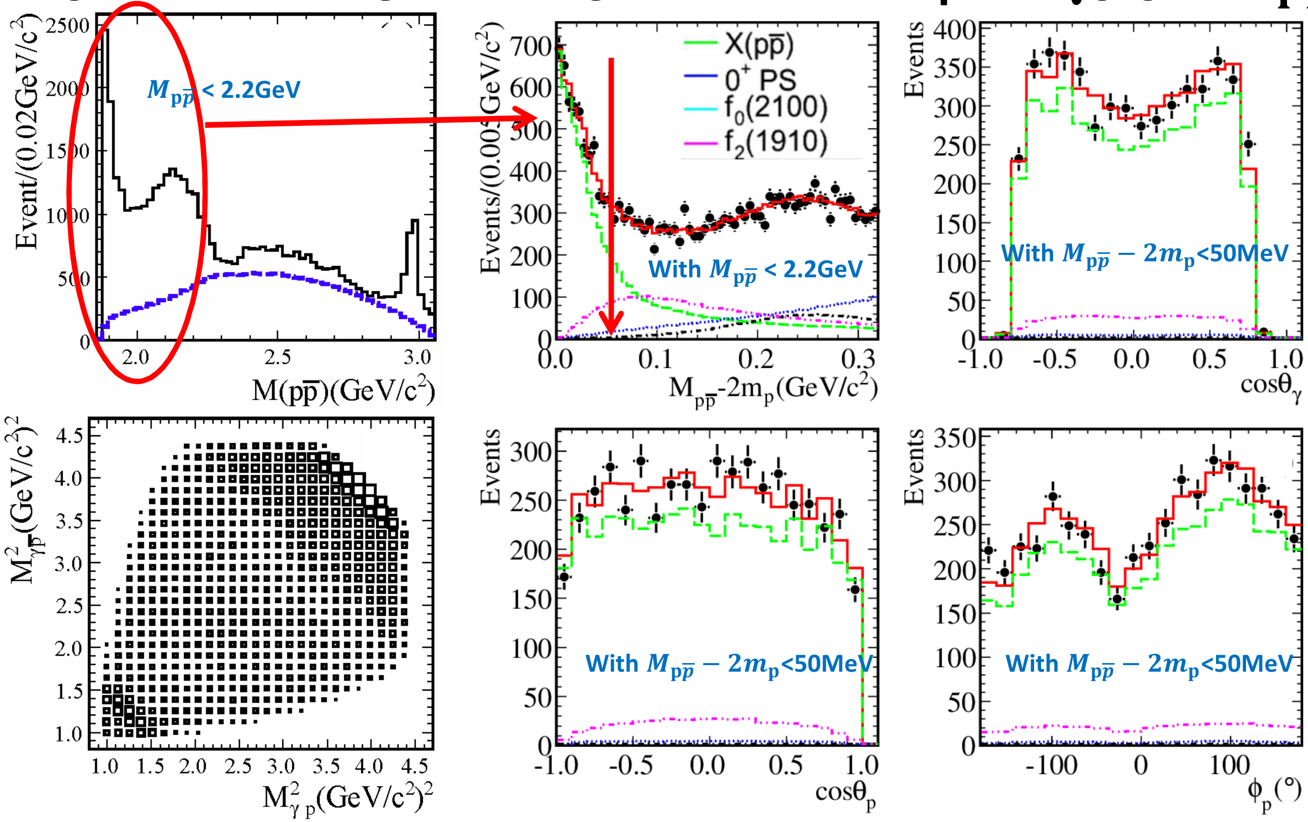
normal meson/ $p\bar{p}$ bound state/multiquark/glueball/Final state interaction effect(FSI)……

Spin-parity analysis

is essential for determining place in the spectrum and possible nature.

PRL 108, 112003 (2012)

Spin-Parity analysis of $J/\psi \to \gamma p\bar{p}$ ($M_{p\bar{p}} < 2.2$GeV)



Four components:
$X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$, and 0^{++} phase space

Include the FSI effect

Fit features:
- The fit with BW and S-wave FSI(I=0) factor can well describe $p\bar{p}$ mass threshold structure.
- It is much better than that Without FSI effect (7.1σ)

Spin-parity, mass, width and Br. of $X(p\bar{p})$:

$J^{PC} = 0^{-+}$ — >6.8 σ better than other J^{PC} assignments.

$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{model})\ \text{MeV}/c^2$

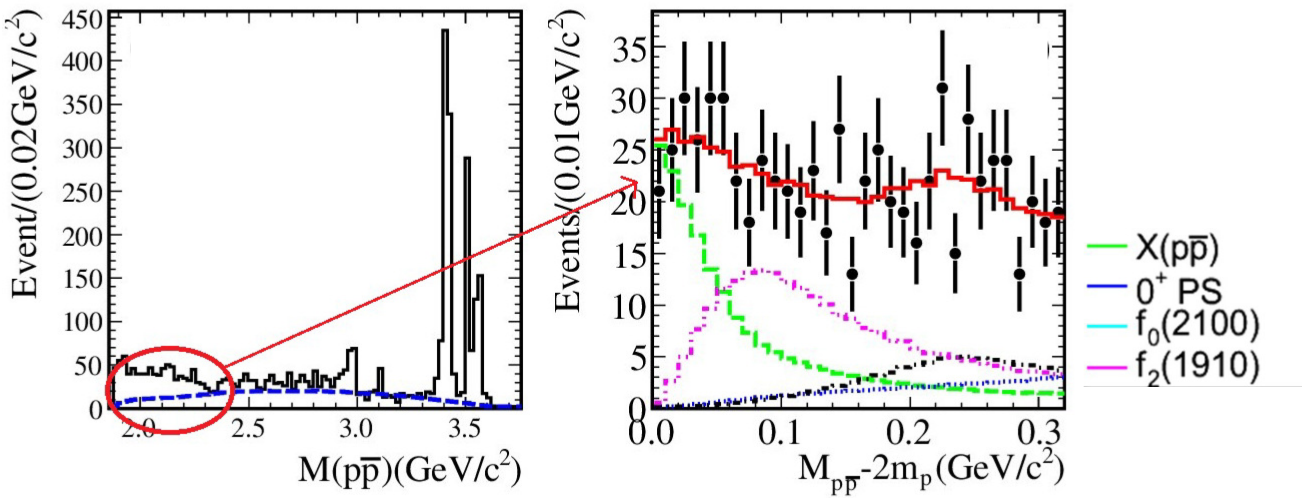
model: Model dependent uncertainty (Different FSI models)

$\Gamma = 13 \pm 39(\text{stat})^{+10}_{-13}(\text{syst}) \pm 4(\text{model})\ \text{MeV}/c^2$ or $\Gamma < 76\ \text{MeV}/c^2$ @ 90% C.L.

$Br(J/\psi \to \gamma X(p\bar{p}))Br(X(p\bar{p}) \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{syst}) \pm 2.3(\text{model})) \times 10^{-5}$

PRL 108, 112003 (2012)

$\psi(2S)\rightarrow\gamma p\bar{p}$ ($M_{p\bar{p}}$< 2.2GeV)



M , Γ and J^{PC} of $X(p\bar{p})$ are fixed to the results obtained from J/ψ decays.

$$Br(\psi(2S)\rightarrow\gamma X(p\bar{p}))Br(X(p\bar{p})\rightarrow p\bar{p}) = (4.57\pm 0.36(\text{stat})^{+1.23}_{-4.07}(syst)\pm 1.28(\text{model}))\times 10^{-6}$$

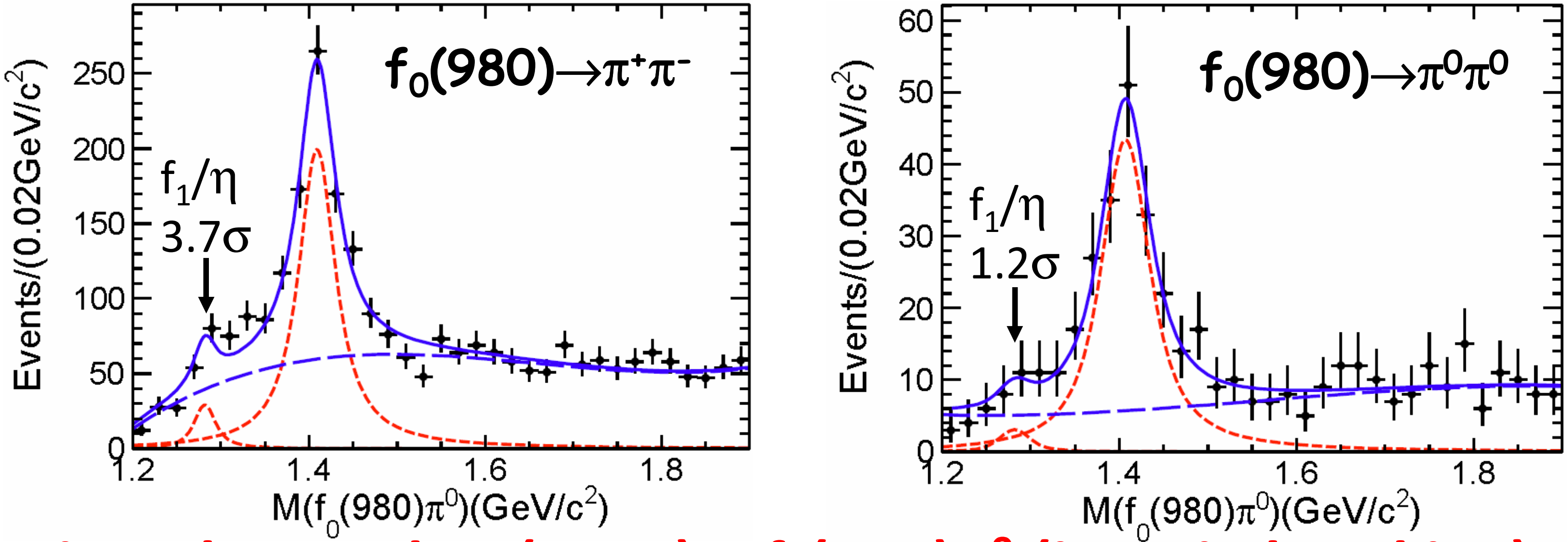
The production ratio R:

$$R=\frac{Br(\psi(2S)\rightarrow\gamma X(p\bar{p}))}{Br(J/\psi\rightarrow\gamma X(p\bar{p}))}=\left(5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(syst)\pm 0.12(\text{model})\right)\%$$

It is suppressed compared with 12% rule.

PRL 108, 182001 (2012)

$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to 2\pi$



First observed: $\eta(1405)\to f_0(980)\pi^0$ (isospin breaking)

- Helicity analysis indicates the peak at 1400MeV is from $\eta(1405)$, not from $f_1(1420)$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat.) \pm 0.11(syst.)) \times 10^{-5}$$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(syst.)) \times 10^{-6}$$

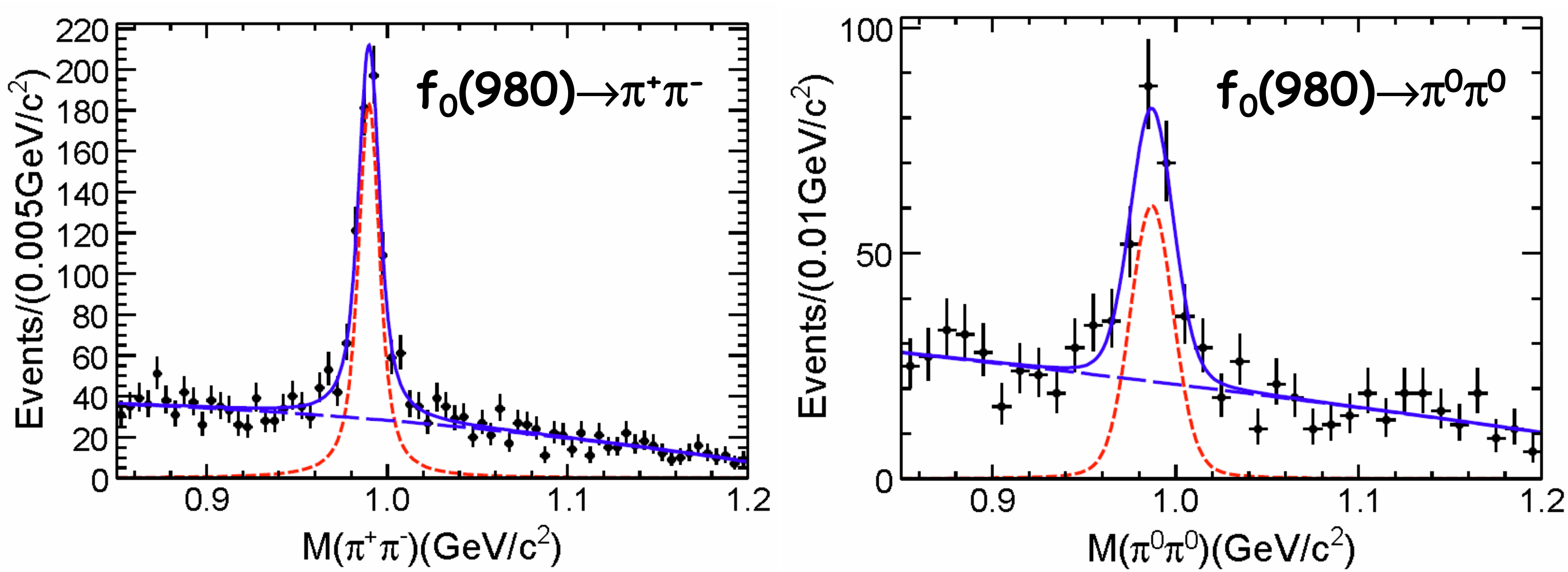
- Large Isospin-violating decay rate:

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

In general, magnitude of isospin violation in strong decay should be <1%.

$a_0 - f_0$ mixing alone can not explain the branching ratio of $\eta(1405)\to f_0(980)\pi^0$

Anomalous Lineshape of $f_0(980)$ in $J/\psi \to \gamma f_0(980)\pi^0$



$M = 989.9 \pm 0.4 \text{MeV}/c^2$
$\Gamma = 9.5 \pm 1.1 \text{ MeV}/c^2$

$M = 987.0 \pm 1.4 \text{MeV}/c^2$
$\Gamma = 4.6 \pm 5.1 \text{ MeV}/c^2$

Surprising result:

very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

A possible explanation is KK^* loop, Triangle Singularity (TS) (J.J. Wu et al, PRL 108, 081803(2012))

PLB 710, 594 (2012)

3π Decays of J/ψ and $\psi(2S)$

$J/\psi \to \pi^+\pi^-\pi^0$ decays are dramatically different from $\psi(2S) \to \pi^+\pi^-\pi^0$ decays:

- J/ψ is dominated by ρ
- $\psi(2S)$ is strongly populated by higher mass state absent in J/ψ decay

Precision measurement of branching fractions:

$$Br(J/\psi \to \pi^+\pi^-\pi^0) = (2.137 \pm 0.004(stat)^{+0.058}_{-0.056}(syst)^{+0.027}_{-0.026}(norm)) \times 10^{-2}$$

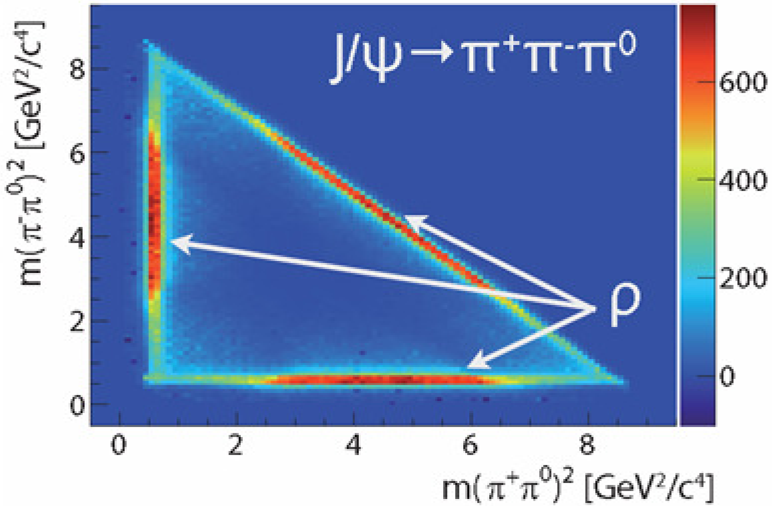
$$Br(\psi(2S) \to \pi^+\pi^-\pi^0) = (2.14 \pm 0.03(stat)^{+0.08}_{-0.07}(syst)^{+0.09}_{-0.08}(norm)) \times 10^{-4}$$

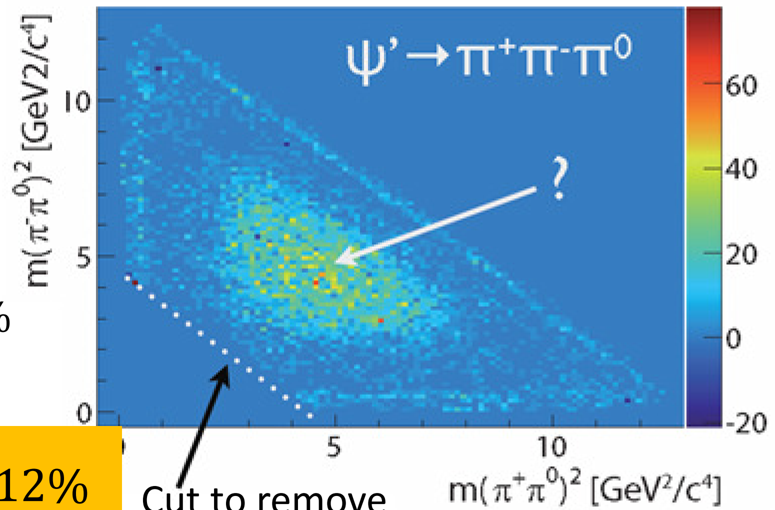
The ratio of these two branching fractions:

$$\frac{Br(\psi(2S) \to \pi^+\pi^-\pi^0)}{Br(J/\psi \to \pi^+\pi^-\pi^0)} = \left(1.00 \pm 0.01(\text{stat})^{+0.06}_{-0.05}(\text{syst})\right)\%$$

$\rho\pi$ puzzle: $Q_h = \frac{Br(\psi(2S)\to hadrons)}{Br(J/\psi \to hadrons)} \cong \frac{Br(\psi(2S)\to e^+e^-)}{Br(J/\psi \to e^+e^-)} \cong 12\%$

Dalitz plot with background subtracted and corrected for efficiency:





Recent Results on Charmonium Physics

- Properties of h_c
- Mass and width of η_c
- Observation of $\psi(2S) \to \gamma\eta_c(2S)$
- First evidence of $\psi(2S) \to \gamma\gamma J/\psi$
- $\chi_{c0,2} \to \gamma\gamma$

Property of h_c (1p1)

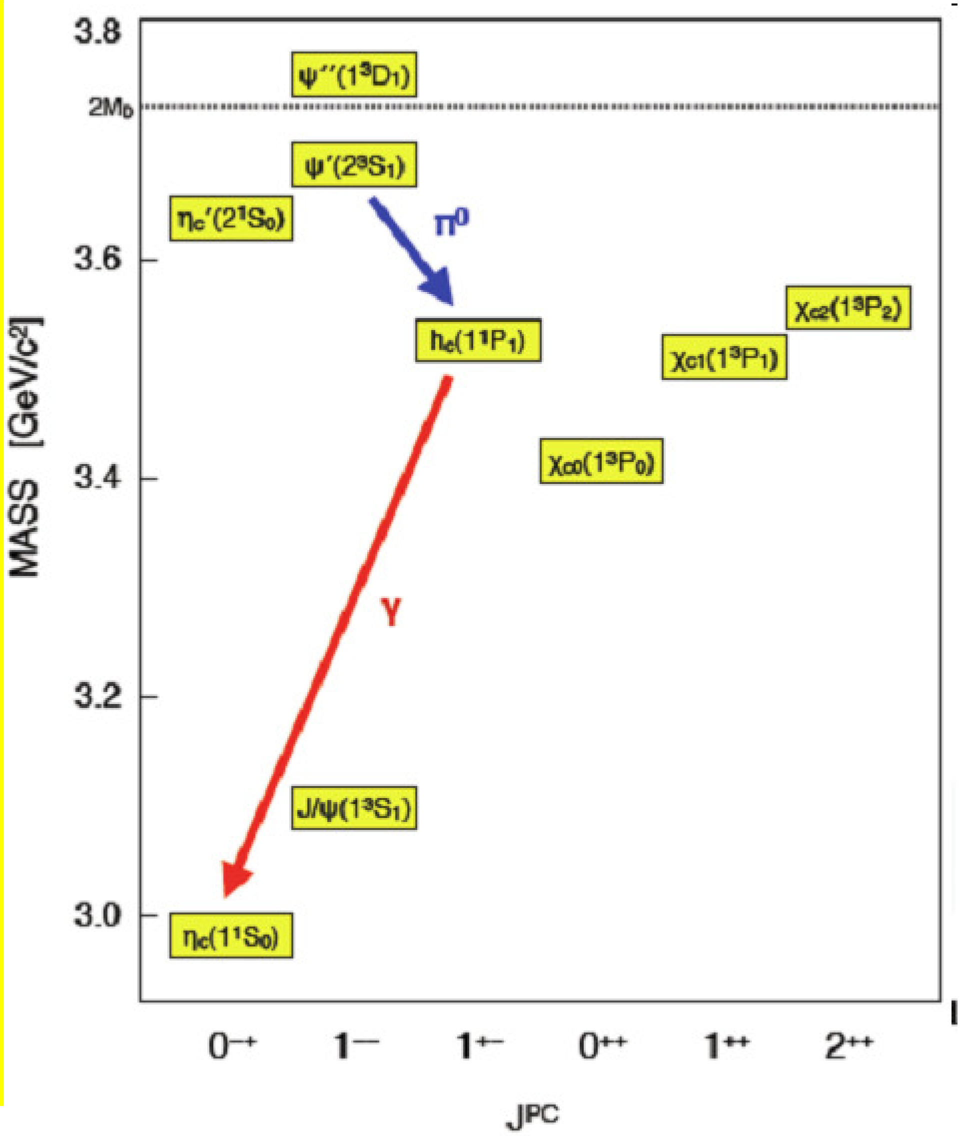
- First evidence:
  E835 in pp→h_c→$\gamma\eta_c$ (PRD72,092004(2005))

- CLEO-c observed h_c in
  ee→$\psi(2S)$→$\pi^0 h_c$, h_c→$\gamma\eta_c$
  $\Delta M_{hf}(1P)=0.08 \pm 0.18 \pm 0.12$ MeV/c^2
  (PRL104,132002(2010))

- Study isospin forbidden transition:
  $\psi(2S) \rightarrow \pi^0 h_c$

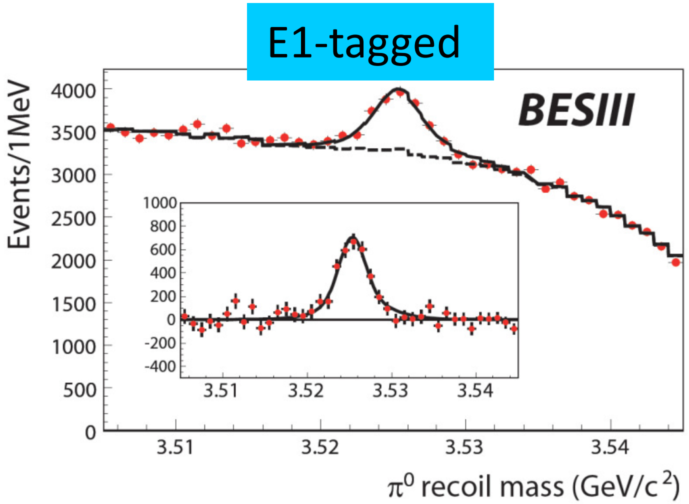
- Measure as well the E1 transition:
  $h_c \rightarrow \gamma\eta_c$

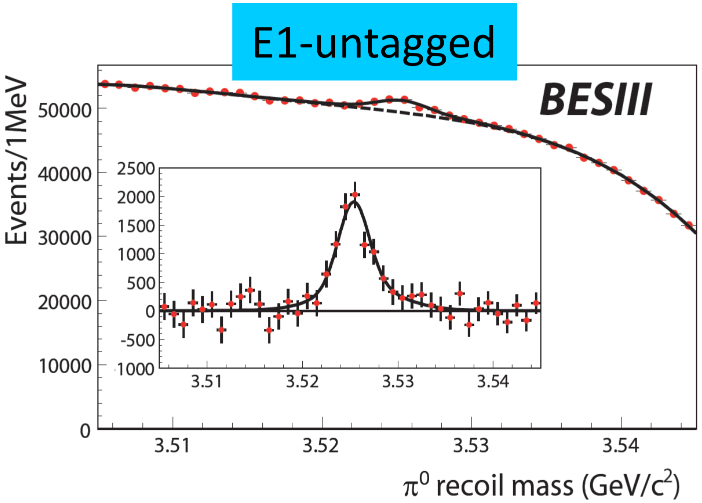
- $M(h_c)$ gives access to hyperfine splitting of 1P states:
  $\Delta M_{hf}(1P) = M(h_c) - 1/9(M(\chi_{c0}) + 3M(\chi_{c1})+5M(\chi_{c2}))$



PRL104, 132002 (2010)

Observation of h_c at BESIII (inclusive)

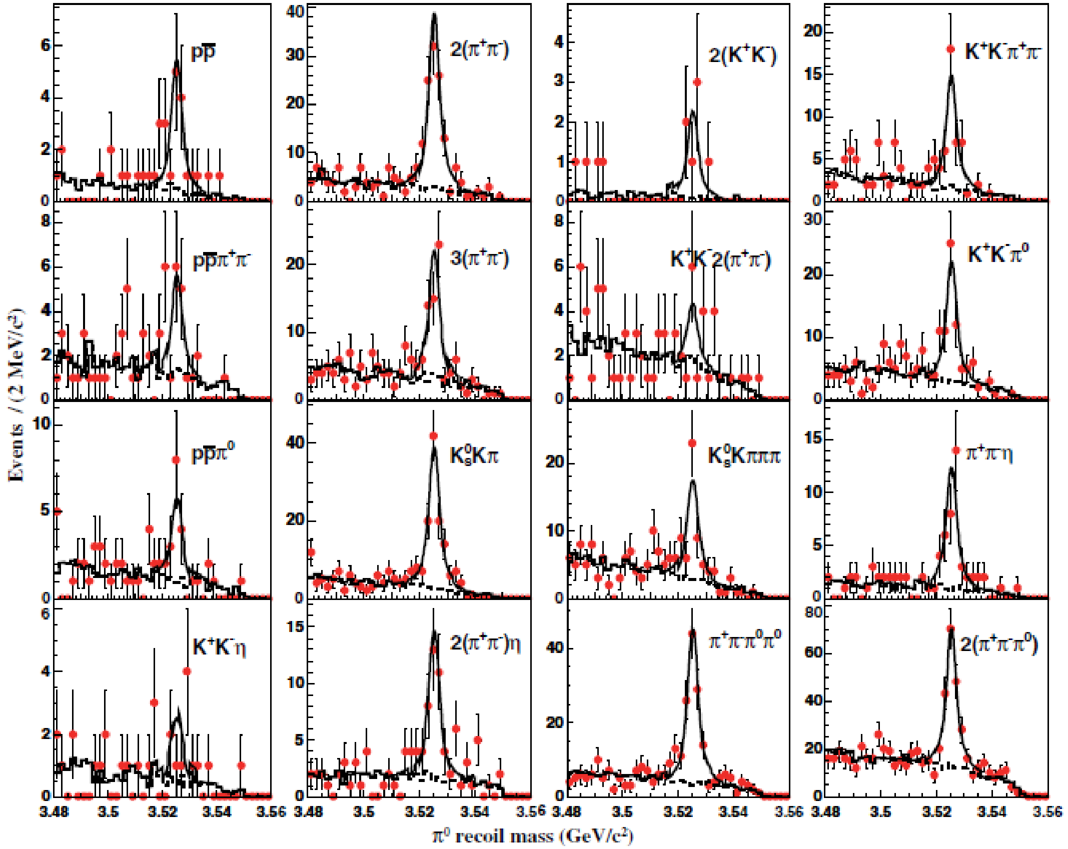




- Select inclusive π^0 ($\psi(2S)\rightarrow\pi^0 h_c$)
- Select E1-photon in $h_c\rightarrow\gamma\eta_c$ (E1 tagged) or not (E1 untagged)
- E1-tagged selection gives
  $M(h_c)$=3525.40±0.13 ±0.18MeV
  ($\Delta M_{hf}(1P)$=0.10±0.13±0.18MeV/c^2)
  $\Gamma(h_c)$=0.73±0.45 ±0.28MeV (first measurement)
  (<1.44MeV at 90% CL)
  $Br(\psi(2S)\rightarrow\pi^0 h_c)\times Br(h_c\rightarrow\gamma\eta_c)$= (4.58±0.40±0.50) ×$10^{-4}$
- E1-untagged selection gives
  $Br(\psi(2S)\rightarrow\pi^0 h_c)$ = (8.4±1.3±1.0) ×10^{-4}
- Combining branching fractions leads to
  $Br(h_c\rightarrow\gamma\eta_c)$ = (54.3±6.7±5.2)%
  (first measurement)

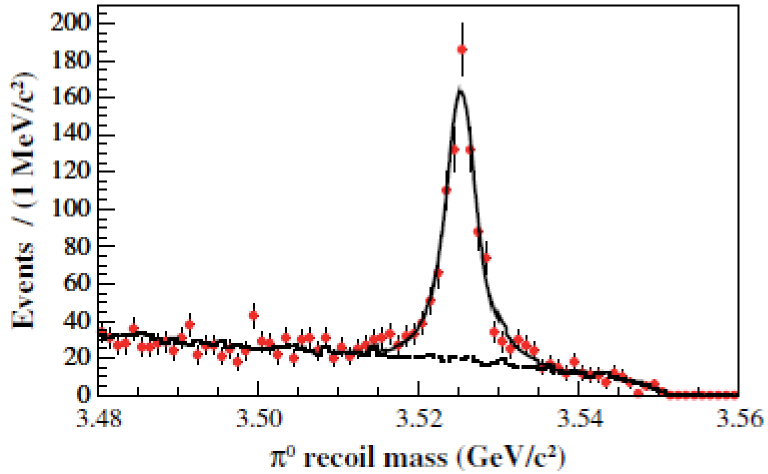
PRD86, 092009 (2012)

Measurements of the h_c properties at BESIII (exclusive)



$\psi(2S)\to\pi^0 h_C$, $h_C\to\gamma\eta_C$,
η_C is reconstructed exclusively with 16 decay modes

Summed π^0 recoil mass

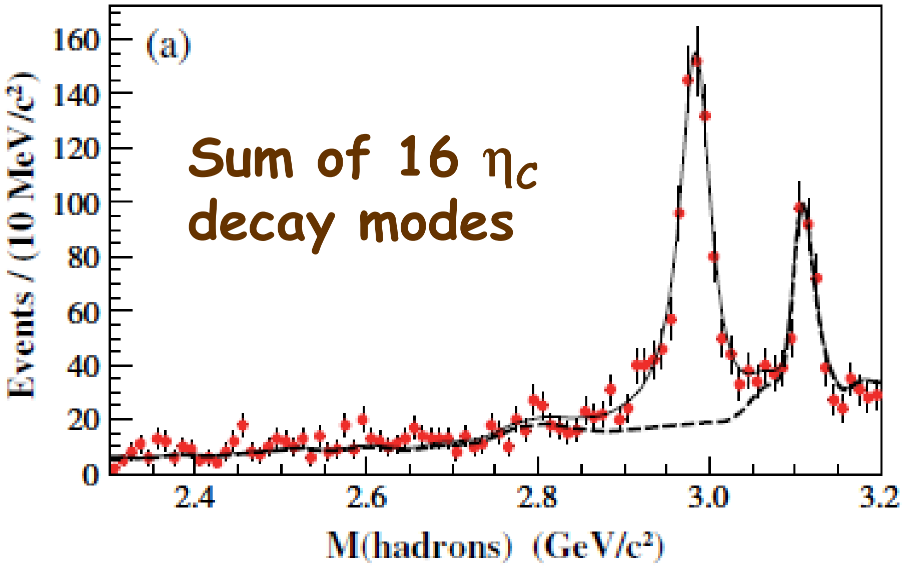


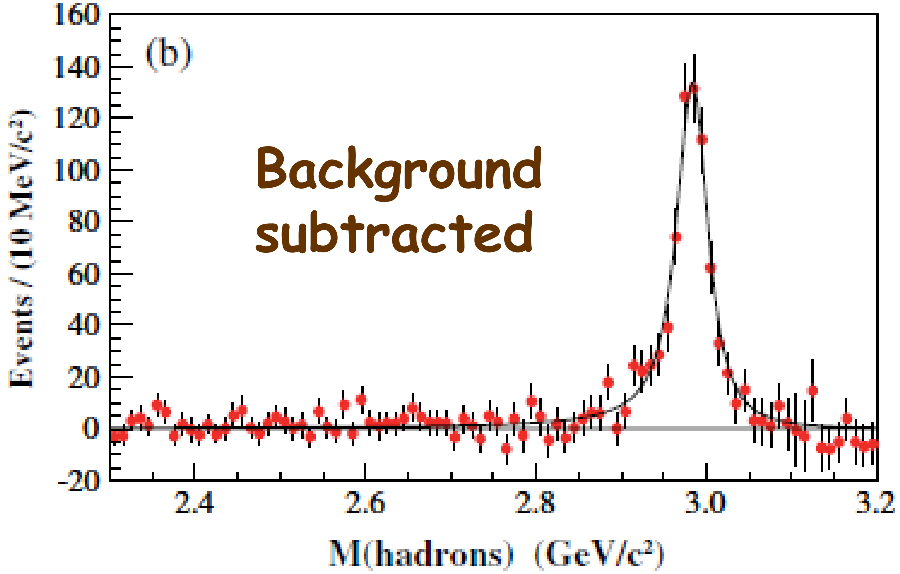
Simultaneous fit to π^0 recoiling mass:
$M(h_c)$ = 3525.31 $\pm$ 0.11 $\pm$ 0.14 MeV
$\Gamma(h_c)$ = 0.70 $\pm$ 0.28 $\pm$ 0.22 MeV
N = 832 $\pm$ 35

Consistent with BESIII inclusive results PRL104,132002(2010)

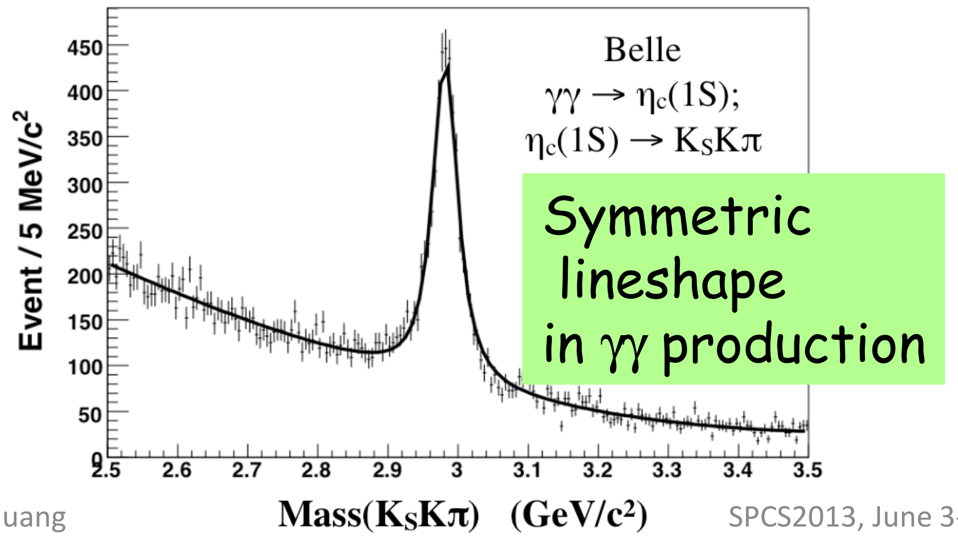
CLEOc exlusive results
$M(h_c)$=3525.21 $\pm$ 0.27 $\pm$ 0.14 MeV/c^2
N = 136 $\pm$ 14
PRL101, 182003(2008)

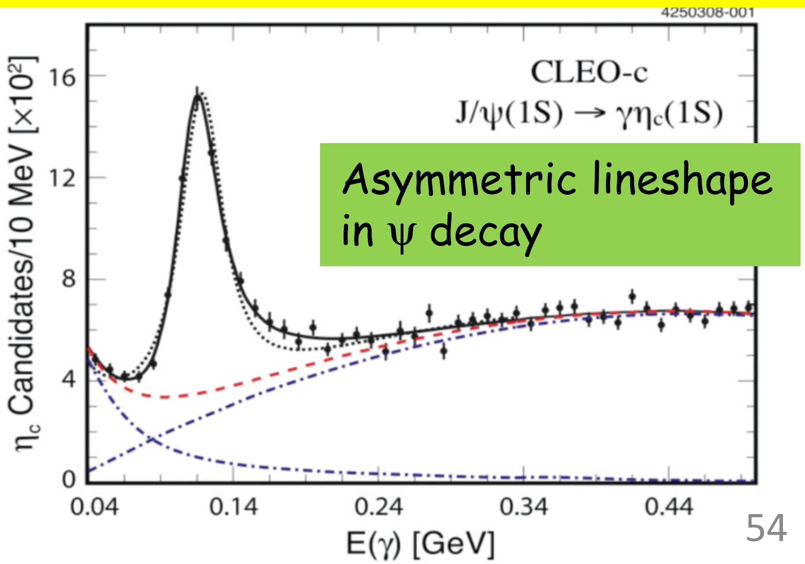
η_c lineshape from $\psi(2S)\to\pi^0 h_c$, $h_c\to\gamma\eta_c$





The η_c lineshape is not distorted in the $h_c\to\gamma\eta_c$, non-resonant bkg is small.
This channel will be best suited to determine the η_c resonance parameters.



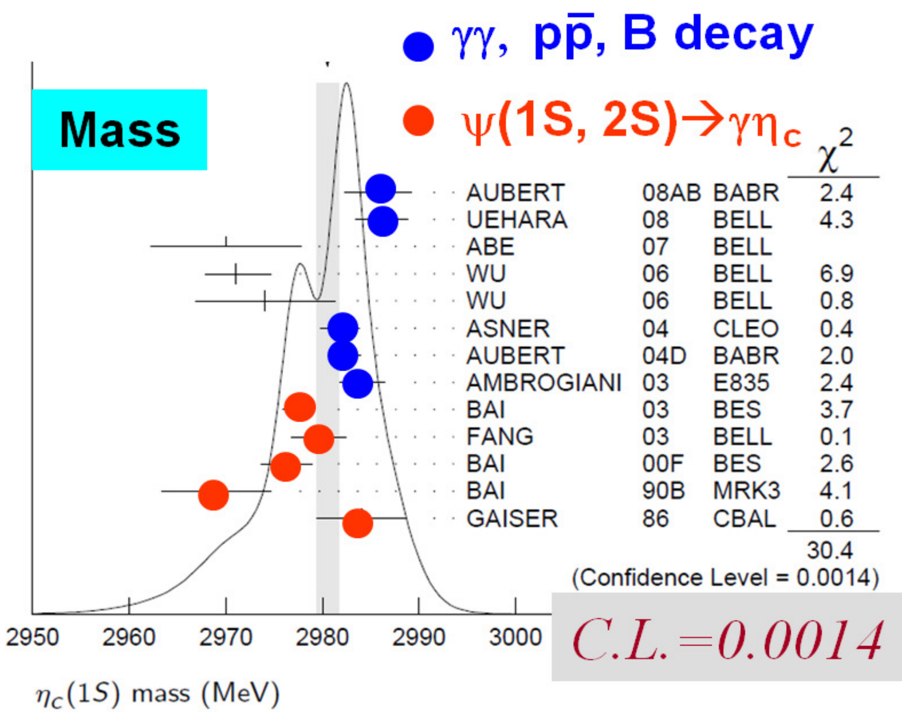


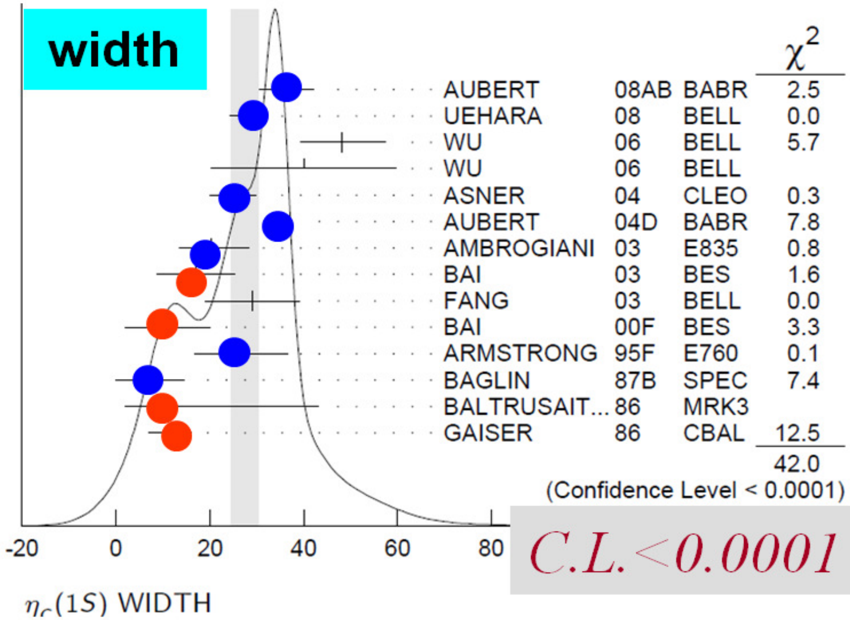
$\eta_c(1S)$

- Ground state of $c\bar{c}$ system, but its properties are not well known:

  J/ψ radiative transition: M ~ 2978.0MeV/c^2, Γ ~ 10MeV

  γγ process: M = 2983.1 ± 1.0 MeV/c^2, Γ = 31.3 ± 1.9 MeV

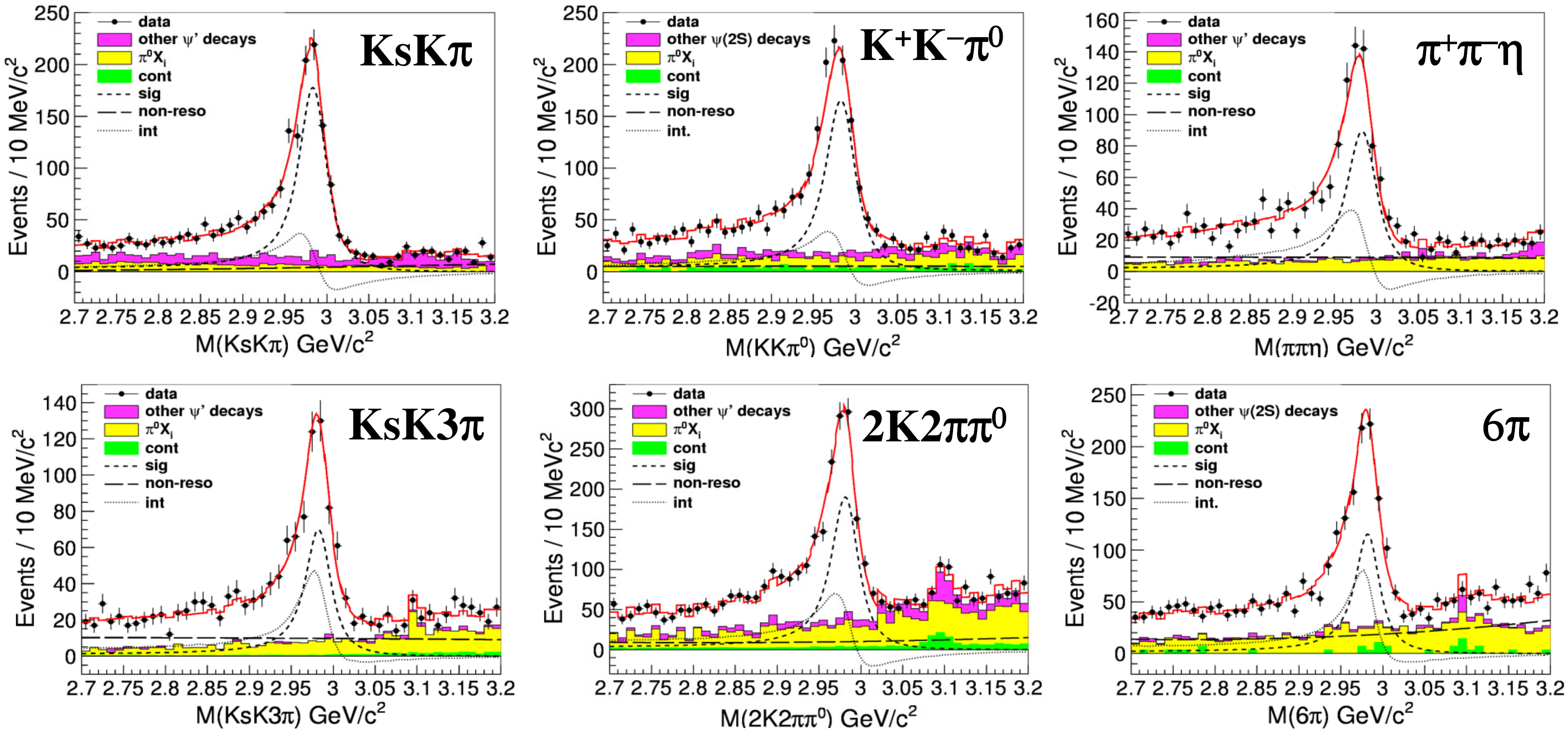




- CLEO-c found the distortion of the η_c lineshape in ψ(2S) decays
- $c\bar{c}$ hyperfine splitting: M(J/ψ)- M(η_c) is important experimental input to test the lattice QCD, but is dominated by error on M(η_c)

PRL108, 222002 (2012)

$\psi(2S) \rightarrow \gamma\eta_c$, η_c exclusive decays



Interference with non-resonant is significant !

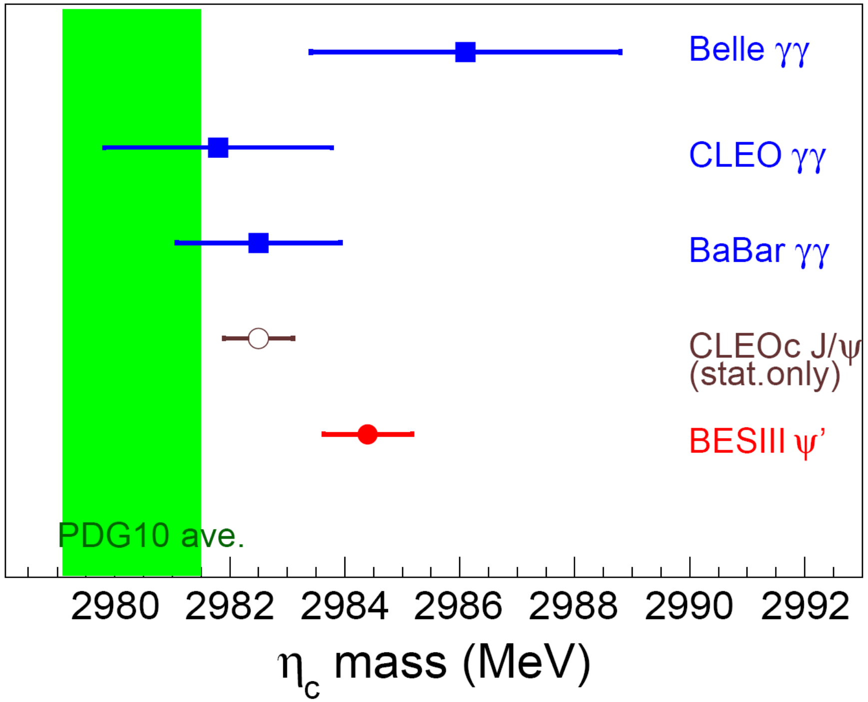
Relative phase ϕ values from each mode are consistent within 3σ,

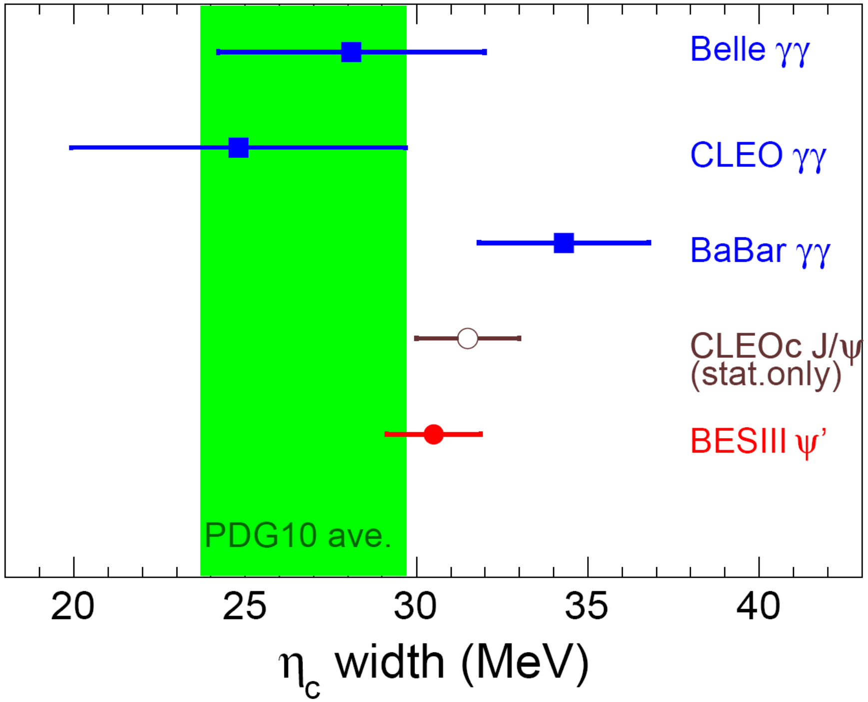
➔ use a common phase value in the simultaneous fit.

Mass: **2984.3±0.6±0.6** MeV/c^2
width: **32.0±1.2±1.0** MeV
ϕ: **2.40±0.07±0.08** rad or
4.19 ±0.03±0.09 rad

Comparison of the mass and width for η_c

The world average in PDG2010 was using earlier measurements





Hyperfine splitting: $\Delta M(1S)$ = **112.6 ± 0.8** MeV

Consistent with B factory results in other production mechanisms.
Agree with lattice QCD calculations of the charmonium hyperfine splitting

$\eta_c(2S)$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi(2S)\rightarrow\gamma X$, never confirmed by other experiments.)

- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^{\pm} \rightarrow K^{\pm}\ \eta_c(2S), \eta_c(2S) \rightarrow K_S K^{\pm}\pi^{\mp}$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \rightarrow \eta_c(2S) \rightarrow K_S K^{\pm}\pi^{\mp}$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \rightarrow \eta_c(2S) \rightarrow K_S K^{\pm}\pi^{\mp}$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \rightarrow J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12\pm3$ MeV

- The M1 transition $\psi(2S)\rightarrow\gamma\eta_c(2S)$ has not been observed.

(experimental challenge : search for real photons ~50MeV,)

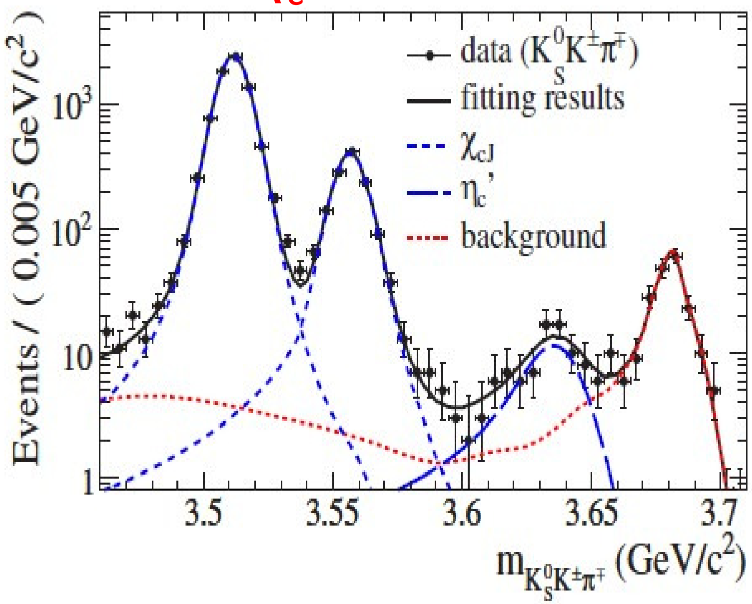
- Better chance to observe $\eta_c(2S)$ in $\psi(2S)$ radiative transition with ~106M $\psi(2S)$ data at BESIII.

- Decay mode studied: $\psi(2S) \rightarrow \gamma\eta_c(2S) \rightarrow \gamma K_S K\pi$ / $\gamma K^+K^-\pi^0$.

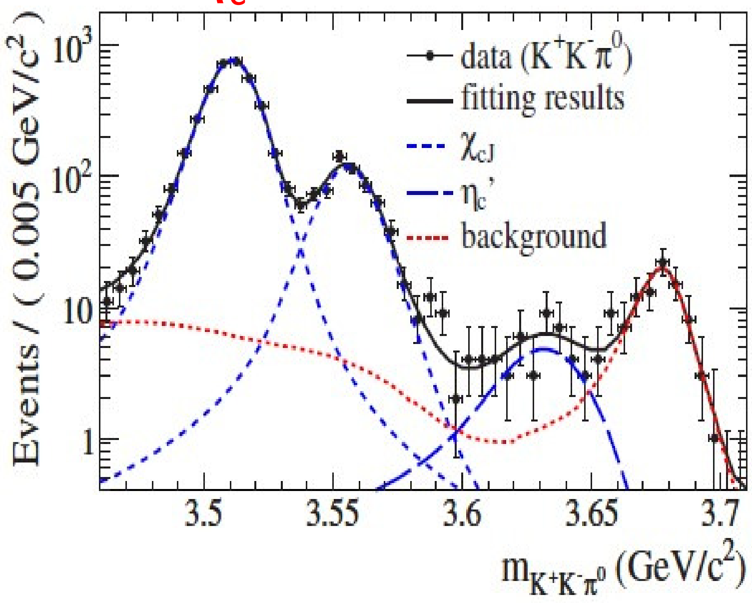
PRL109, 042003 (2012)

Observation of $\psi(2S)\rightarrow\gamma\eta_c(2S)$

$\eta_c(2S)\rightarrow KsK\pi$



$\eta_c(2S)\rightarrow K^+K^-\pi^0$



Statistical significance > 10σ

- Simultaneous fit with:
  - $\eta_c(2S)$ signal: modified BW (M1) with fixed width (Resolution extrapolated from χ_{cJ})
  - χ_{cJ} signal: MC shape smeared with Gaussian
  - BG from $e^+ e^- \rightarrow KK\pi$ (ISR), $\psi(2S) \rightarrow KK\pi$ (FSR), $\psi(2S) \rightarrow \pi^0 KK\pi$: measured from data

Results on $\psi(2S)\to\gamma\eta_c(2S)\to\gamma KK\pi$

- $M(\eta_c(2S)) = 3637.6 \pm 2.9 \pm 1.6$ MeV/c^2
- $\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8$ MeV
- $Br(\psi(2S)\to\gamma\eta_c(2S)\to\gamma KK\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$

$Br(\eta_c(2S)\to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$ from BaBar

$$Br(\psi(2S)\to\gamma\eta_c(2S)) = (6.8 \pm 1.1_{stat} \pm 4.5_{sys}) \times 10^{-4}$$

CLEO-c: $<7.6\times10^{-4}$ PRD81,052002(2010)

Potential model: $(0.1\text{–}6.2)\times10^{-4}$ PRL89,162002(2002)

60

ψ(2S)→ γγJ/ψ

- Two photon transitions are well known in excitations of molecules, atomic hydrogen, and positronium.

  *[F. Bassani etal, PRL **39**, 1070 (1977);A. Quattropani etal, PRL **50**, 1258 (1983)]*

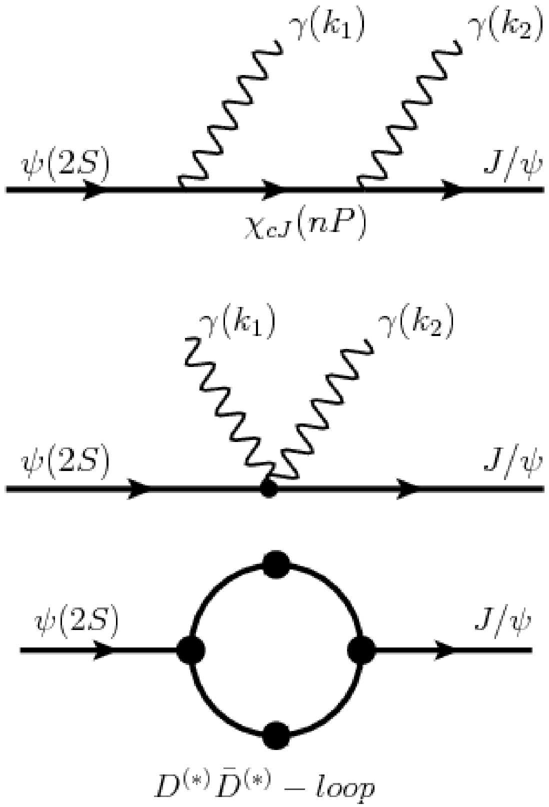
- Never been observed in the quarkonium system.

  CLEO-c: upper limit of $Br(\psi(2S)\to \gamma\gamma J/\psi)$ is 1×10^{-3} (PRD 78,011102(2008))

- Observation helpful to understand heavy quarkonium spectrum & strong interaction

Theoretically:

- Potential models give discrete spectra ($\psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$)
- Possibility of testing the hadron-loop effect
- Coupled channel: **the hadron-loop effect also may play a important role in the continuous spectra**

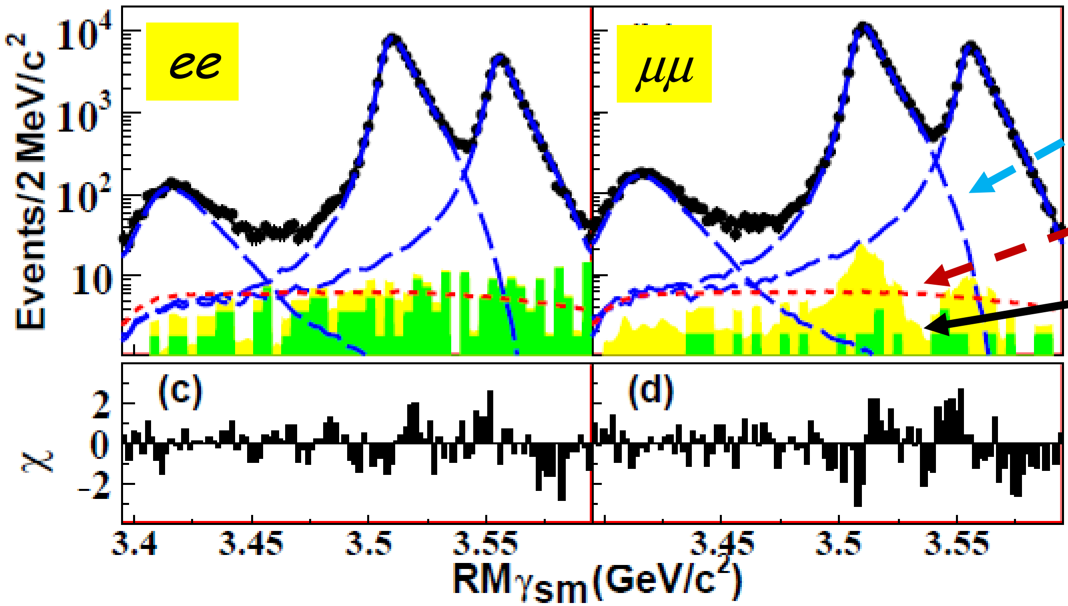


PRL109, 172002 (2012)

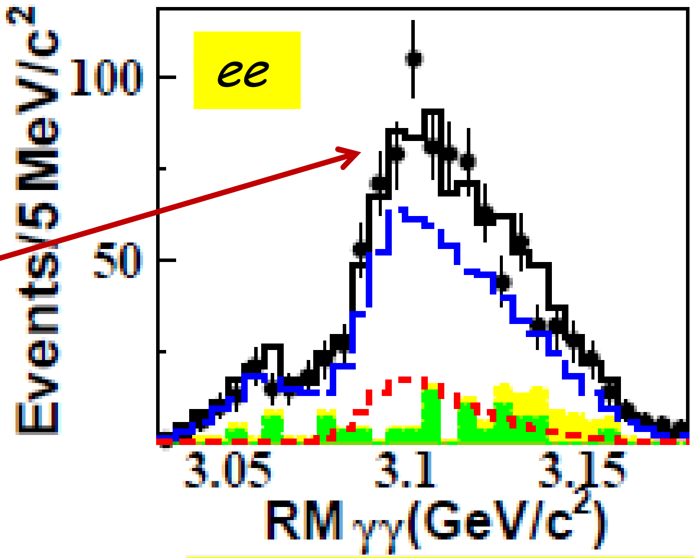
First evidence of $\psi(2S) \to \gamma\gamma J/\psi$

- Select $\psi(2S) \to \gamma\gamma J/\psi$, $J/\psi \to e^+e^-$ and $\mu^+\mu^-$ events

γ_{sm} - **low energy gamma**



- the χ_{cJ} components: double E1 scaling
- yields of the two-photon events
- continuum(green) + $\psi(2S)$ decay BG(yellow)



3.44<RM(γ_{sm})<3.48GeV

- Global fit of the two-photon process and cascade χ_{cJ} processes
- See **clear excess** over BG + continuum

- *Br*($\psi(2S) \to \gamma\gamma J/\psi$) = $(3.3 \pm 0.6^{+0.8}_{-1.1})$ x 10^{-4} (both *ee* and $\mu\mu$)

- **Significance : 3.8σ including systematics**

- *Br*($\psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$) are also measured

PRD 85, 112008 (2012)

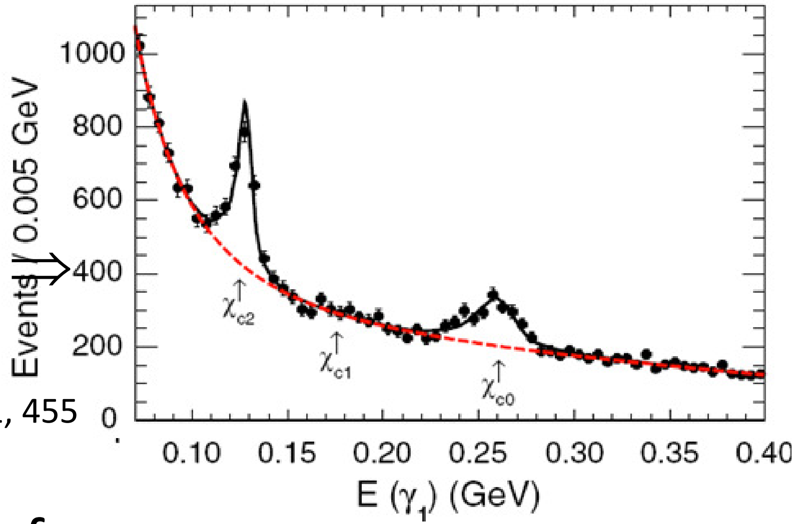
$\chi_{c0,2} \rightarrow \gamma\gamma$

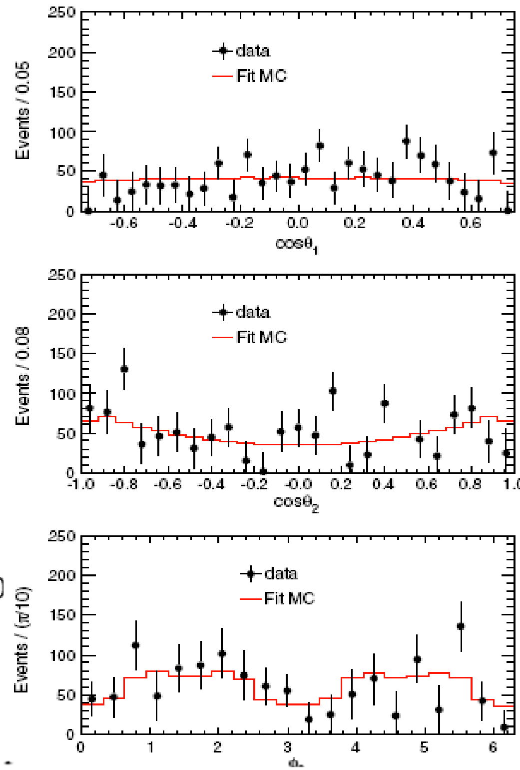
- In analogy to the ^3P positronium decays
  - $R \equiv \Gamma(^3P_2 \rightarrow \gamma\gamma) / \Gamma(^3P_0 \rightarrow \gamma\gamma) = 0.27$
- First-order QCD radiative correction ⇒ $R = 0.116 \pm 0.010$

(Voloshin, Prog. Part. Nucl. Phys. 61, 455 (2008))

- First measurement of $f_{0/2} \equiv \Gamma^{\lambda=0}(\chi_{c2} \rightarrow \gamma\gamma) / \Gamma^{\lambda=2}(\chi_{c2} \rightarrow \gamma\gamma)$
- Relativistic potential model ⇒ $f_{0/2} < 0.5\%$

(T. Barnes, in Proceedings of the IX International Workshop on Photon-Photon Collisions)



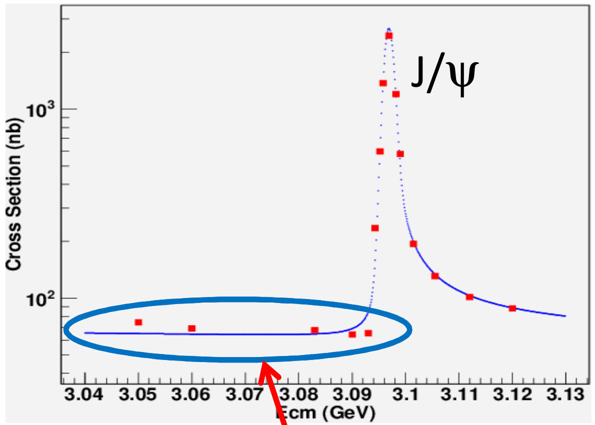


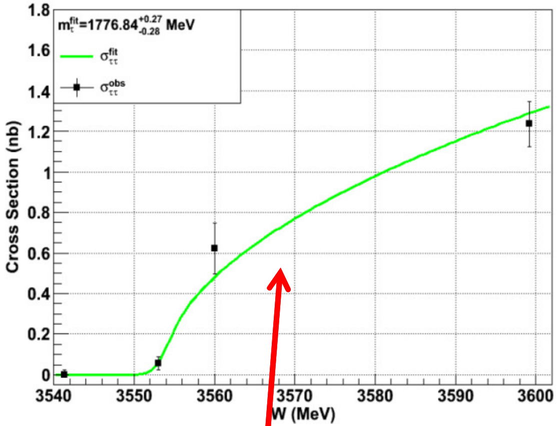
Quantity	PDG global fit results	This measurement[b]
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c0})^c$	2.16 ± 0.18	$2.17 \pm 0.17 \pm 0.12$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c2})^c$	2.24 ± 0.17	$2.81 \pm 0.17 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c0})^c$	2.23 ± 0.17	$2.24 \pm 0.19 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c2})^c$	2.56 ± 0.16	$3.21 \pm 0.18 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c0})$ (keV)	2.32 ± 0.22	$2.33 \pm 0.20 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c2})$ (keV)	0.50 ± 0.05	$0.63 \pm 0.04 \pm 0.06$
$\mathcal{R}$	0.22 ± 0.03	$0.27 \pm 0.03 \pm 0.03$
$f_{0/2}$	...	$0.00 \pm 0.02 \pm 0.02$

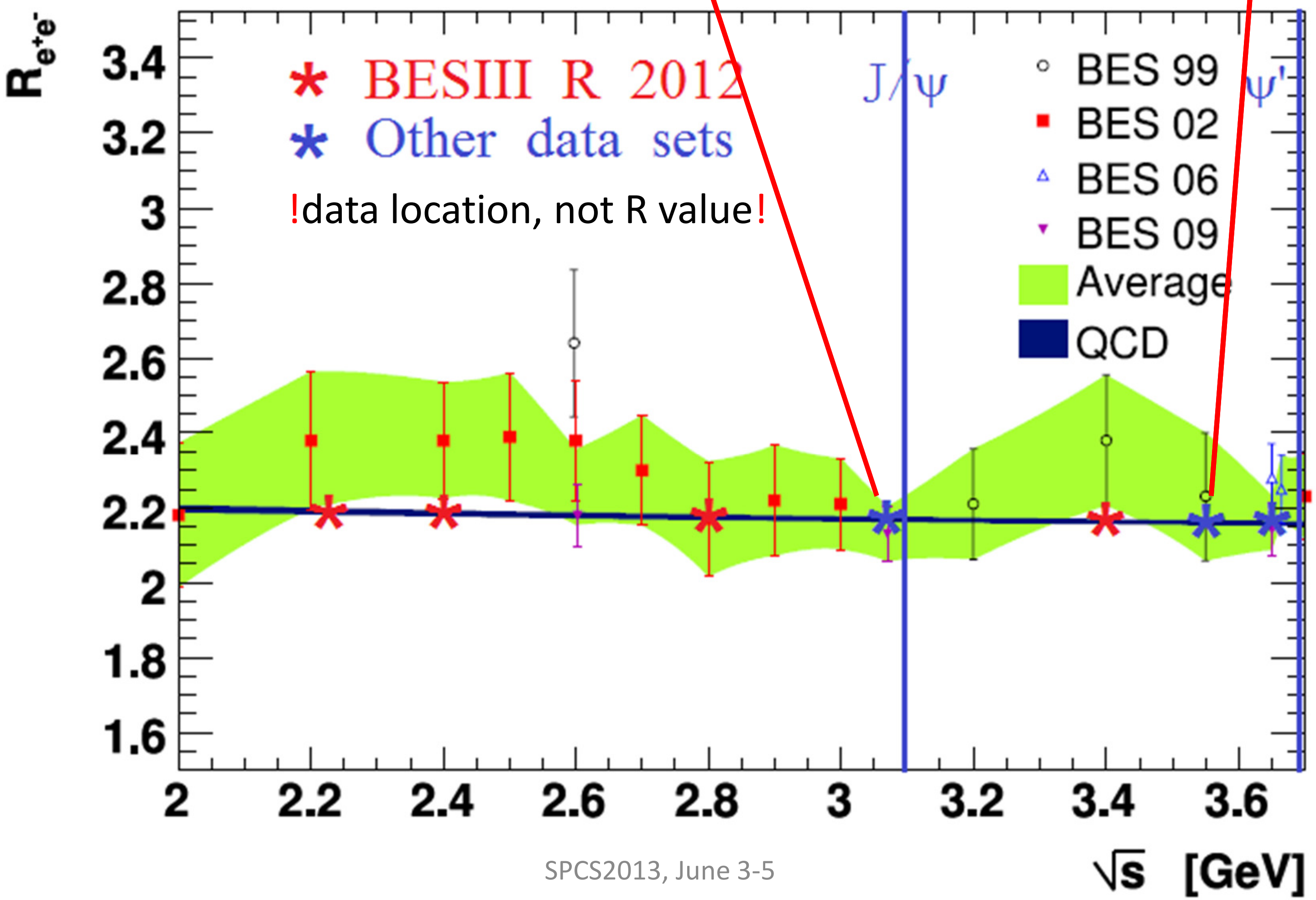
R measurement and QCD study

First R-QCD run

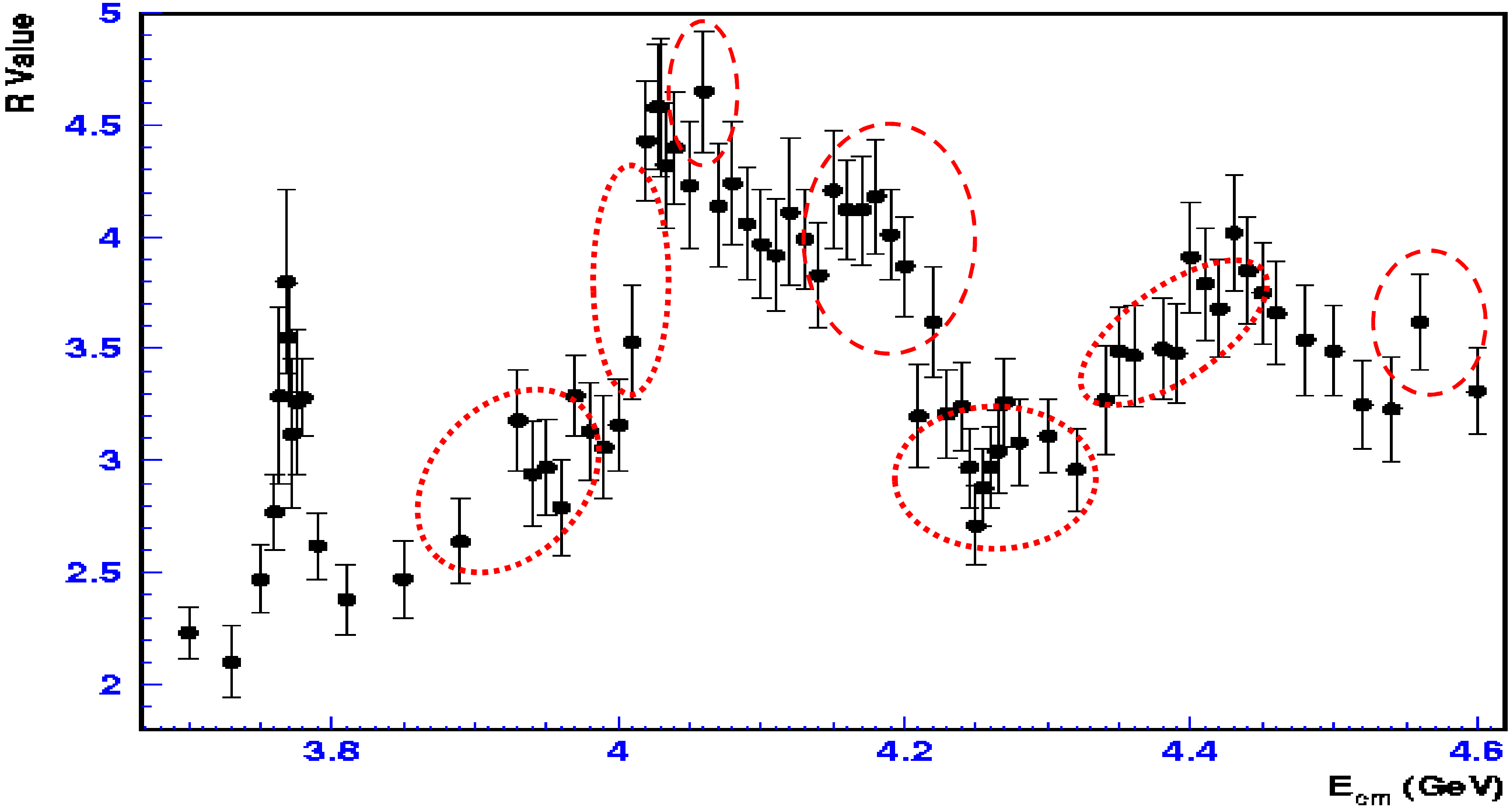
Data collected at 2.23, 2.4, 2.8 and 3.4 GeV in June, 2012.







Detail scan in high mass charmonia region planned



- What are these broad resonances?
- Mass resgion where some X, Y, Z particles are found.
- Possible new resonance that not yet discovered?